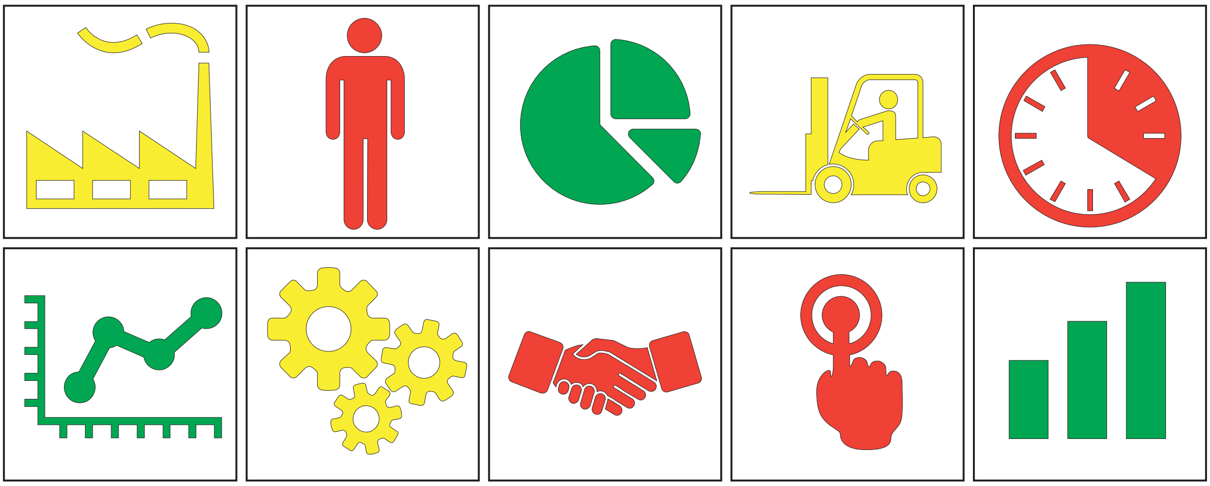

Introducing standardization to achieve a more efficient manufacturing – in collaboration with Santa Maria-Mölndal

Master of Science Thesis in the Master's Degree Programme, Production Engineering

Mary Kawoogh

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Department of Technology Management and Economics

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CHALMERS UNIVERSITY OF TECHNOLGY

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Abstract

This Master's thesis was conducted in 2012 as a part of the examination from the Master's programme Production Engineering at Chalmers University of Technology. It deals with reducing waste at the leading taco manufacturer in Sweden, Santa Maria-Mölndal, with the main purpose of increasing the productivity and reducing the production costs.

Every year, approximately 327.2 tones of chips are disposed due to various problems in the taco production. This corresponds to a large amount of waste in monetary terms, which is desirable to reduce. By mainly using Lean production principles as guidelines, waste in the production was discovered, reviewed and eliminated virtually. Discrete Event Simulation, with the software AutoMod, was used throughout the project as an analytical tool to simulate the current production line. A current state simulation was produced with the aim of identifying bottlenecks and other types of problems, and different possible solutions were tested virtually.

Further, the overall work instructions at Santa Maria-Mölndal lacks standardization, which partly contributes to today's inefficient production process. Mostly the changeovers are unstructured and time consuming. Another major part of the project has therefore been creating standardized work instructions for the current manual workstations. A few stations, which consist of repetitive work tasks, were selected for productivity analysis with SAM (Sequential Activity-based Method) for standardization purposes. Apart from creating standards, the Lean philosophy and different Lean principles were used as analytical tools throughout the analysis for creating a more efficient production flow.

Lastly, possible solutions to the various problems were developed, analysed and cost estimated. The vitality of the possible improvements and the implementation possibilities were also reviewed critically based on the company's possibilities to meet the required costs and resources. Some of the solutions could be tested virtually in the simulation to predict the outcome that was later compared to reality.

Keywords: Lean production, Productivity, Improvement work, Discrete Event Simulation, AutoMod, Standardized work, Standardization, Taco production, Santa Maria-Mölndal

Acknowledgements

This Master's thesis has been conducted at the department of Technology Management and Economics at Chalmers University of Technology. The project's focus on improving and standardizing the taco production was given by Santa Maria-Mölndal.

Firstly, special appreciation is given to Björn Amneus at Santa Maria-Mölndal who enabled and interestingly participated with positive reception. Special thanks are also given to all employees at the company, allowing the authors to freely occupy their time for interviews, discussions and, analyses.

At Chalmers University of Technology the authors would like to thank their supervisor Ola Hultkrantz for his participation and helpful guidance throughout the project. Also, the own initiative of using Discrete Event Simulation required instant expertise help at the department of Product and Production Development – the authors are therefore grateful for Erik Lindskog's offer of voluntarily helping with the simulation parts of the project.

Göteborg, 11 June 2012

Mary Kawoogh

Pooyan Seddighzadeh

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1. Introduction

The following chapter presents the background of the Master's thesis and formulates the current problems at Santa Maria-Mölndal, further referred to as Santa Maria. The main purpose of the project and its limitations are specified and discussed. Further, an initial problem analysis is conducted as a baseline for future analyses.

1.1 Background

Working towards a more efficient production with high flexibility to meet the market demand is an obvious trend within manufacturing companies (Liker, 2004). A great deal of pressure to increase the productivity is constantly placed on todays manufacturing companies to survive in relation to their competitors. The main focus of this Master's thesis is to increase the productivity in the factory and reduce the production costs for Santa Maria.

One of the major drivers for improvement work at Santa Maria is that the leadership of the company has discovered economical losses, mainly caused by the production processes. Currently, there is a lot of waste in the factory, especially visible in the chips production line. Every year, approximately 327.2 tones of chips are disposed due to several known and unknown production related problems, which are analysed later on. This corresponds to a large amount of waste in monetary terms, which could be used elsewhere.

The chips production process at Santa Maria was totally reconstructed during 2004, with the aim of tripling the capacity. The previous chips production design created the opportunity to store excessive chips in different kinds of manual buffers, which were returned to the process. The reconstruction of the chips production line resulted in increased capacity and waste. According to previous decisions made at the company, the handling costs for manual buffers for leftover products were high. The situation was considered unhygienic and was not profitable in the long run. This resulted in today's situation where a huge amount of chips become waste during the process.

The chips production line is mostly automated; the amount of manual work that occurs constitutes of operators observing the production and intervening whenever needed. The work instructions at Santa Maria are not standardized, which partly contributes to today's inefficient production process. The changeovers are unstructured and time consuming and are also in need of standardization.

1.2 Purpose

The main purpose of this project is to analyse and improve the existing chip production line. The initial approach is to locate, review and eliminate waste in the factory and hence reduce the production costs and increase the productivity for Santa Maria.

As mentioned earlier, there are no standardized work instructions for the operators, which contribute to the inefficient production. In order to structure and standardize the work, the manual procedures need to be reviewed with the aim of creating standardized work instructions.

1.3 Limitations

This thesis takes place at Chalmers University of Technology and Santa Maria in Mölndal, Göteborg. It covers only aspects regarding the chips production line at Santa Maria. Process-related problems will mainly be considered while problems related to the work organization or motivational problems are of secondary priority.

The aspects of human factors in production are given a less priority. As described earlier, most of the chips production line is automated which in turn minimizes the number of repetitive work tasks. The suggested solutions in this project are based on the company's possibilities to meet the required costs and resources.

1.4 Problem analysis

Every year 327.2 tones of chips are disposed at the Santa Maria factory due to several causes. The main observed cause is that the production process is not efficiently designed. The production line can be divided into two main sections including various processes and buffers. The first section consists of processes manufacturing chips, and the second section consists of different packaging and wrapping equipment. There is no opportunity to store excessive chips between the chips production section and the packaging section. The packaging section encounters several obstacles and problems, and is in constant need of observing and handling.

The packed chips bags need to be passed through a controlling process for quality assurance. The controlling station includes metal detecting and further discards every bag of chips that does not fulfil proper weight and air pressure specifications. This causes an additional amount of chips for disposal.

Manual work occurs in some parts of the automated chips production, such as replenishing raw material and dealing with unplanned problems. The chips production line, which has three shifts, is staffed with three operators per shift. The lack of standardized work instructions for the manual operations is one main reason of today's inefficient production. Similarly, the changeovers are in lack of standardization, which results in unstructured and time consuming procedures during the production.

Further problems that have been observed are more related to the psychosocial field, namely the surrounding work environment. The factory is today rather small and the existing equipment contributes to a high-temperature work environment. With an expanded production due to several factors, such as increased customer demand, the factory is also crowded. It should not be neglected that working under these circumstances is difficult and might reduce the work motivation; hence operators might perform less than average.

2. Company Profile

This chapter is divided into two parts. The first part presents the background of the company in focus, Santa Maria and the second part describes a thorough production process flow that is used later on for further analyses.

2.1 Santa Maria

Santa Maria was established in 1911 in Sweden as a family-owned company with the former name Nordfalks AB. In 2001, the company had expanded and reached Europe. Also the name of the company was changed into today's well-known brand Santa Maria AB (Santa Maria, 2012).

Santa Maria AB is the market leader of spices and flavouring in Scandinavia, and one of the market leaders in Europe, with more than 1400 employees. The company is a part of the Paulig Group, which is an international enterprise in the food industry. Santa Maria's products constitute of spices, barbecue products, Tex Mex products, Indian food and Thai food. Their goal is to become the market leader of their products in Northern Europe (Santa Maria, 2012). The remaining members of the Paulig Group are Oy Gustav Paulig AB, Lihel AB, Ingredia AS and Nordfalks Industri AB (Paulig Group, 2012), figure 1.

Santa Maria AB has three plants in Sweden; two in Mölndal and one in Vadensjö. The headquarters is located in Mölndal where spices are produced. The production of Tex Mex-products is split between the second plant in Mölndal and the plant in Vadensjö (Bengtsson and Johansson, 2008). The project takes place at the Tex Mex factory in Mölndal where taco chips, shells and tubs are produced.

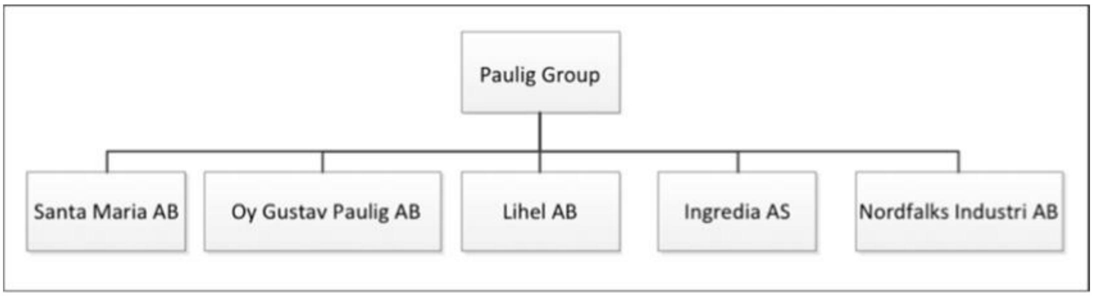

Figure 1: The Paulig Group (Paulig Group, 2012).

2.2 Production process flow

The production line for taco chips manufacturing at Santa Maria can be divided into two main sections including various processes and buffers. The first section consists of machine groups producing and baking chips, and the second section consists of different packaging and wrapping equipment. The baking section in turn consists of the main processes, mixing, rolling, forming, baking, air-drying, frying and finally flavouring, Appendix A, table 1.

2.2.1 Section 1 – Chips manufacturing

The chips manufacturing is initiated by a *mixing process,* where the ingredients of the product, i.e. salt, water and corn flour, are mixed together for further processing into dough. The mixing process consists of two mixing chambers; one chamber is used for mixing the ingredients into finished dough, while the second chamber is used for storing the finished dough before passing it on to the next operation. The two chambers enable simultaneous processing of approximately 215 kilos dough per chamber.

Immediately after the mixing operation, the dough is passed on to a *rolling operation* where it is rolled into thinner layers and is therefore prepared for the subsequent *forming process*. The rolling operation is carried out by pressing the dough between two rolling wheels, which create the possibility to set predetermined thickness on the dough layer.

The rolled dough is formed into its final shape during the subsequent forming operation. The thin dough is then passed below a forming wheel consisting of differently shaped knives, which cuts out the final shaped chips. Triangular, circular and rectangular shapes are the optional forms that can be installed in the forming equipment. It is worth mentioning that the triangular shape is the most commonly used one, followed by the circular shape. Since the chips are cut out, the remaining dough is automatically returned to the forming operation and can be reused.

The formed chips are then transported into the oven for the *baking process*. The oven consists of three parallel conveyors that all chips pass through during the baking process. Chips exiting the baking process are not entirely finished; the texture is a crispy surface and a softer inside. The subsequent operation, the *air-drying process*, consists of five parallel conveyors, where the chips pass through to even out the quality and hence obtain a uniform texture.

The crispy chips are then lowered into an oil bath during the *frying process*. All fried chips are then transported to the last operation for flavouring before moving on to the packaging section. Flavouring occurs in three parallel flows, which creates the possibility to produce different product types in parallel. The variation between the product types can differ in packaging size and the type of flavour added to the chips. A detailed overview of the chips manufacturing section is available in Appendix A, table 1.

2.2.2 Section 2 – Packaging

The packaging section consists of all processes that are a part of the packaging and wrapping of the products before delivery to the customer. There are two different automated lines producing different packaging sizes, 200 g and 500 g, and product types. Further, there is a manual packaging line used to produce a specific product package.

The two automated packaging lines have a similar layout and processes, starting with a *sealing process*. During this initiating operation, a predestined amount of chips is released into a plastic bag, which is cut and sealed. Furthermore, the sealed chips bags move on to a *controlling process* consisting of a metal detector, weight and air-pressure controller, where they are inspected. The metal detector discards the bags containing metal parts; these might be machine parts that accidently end up in the production process. If the weight is less than it should be, the bag is discarded. Similarly, if the air pressure differs from what it should be, i.e. is too high or too low, the bag is also discarded. This is due to the product quality assurance; if the air pressure is too low the chips will be smashed during packaging and transportation, and if it's too high the bag will instead crack open.

The smaller variant of the chips bags are in the next station, the *packaging process*, sorted in a predestined number and placed cardboard-boxes, which in turn are folded and glued around the chips bags. The boxes containing the final products to the customer are then labelled and transported to a *palleting process*.

The larger variant of the chips bags are directly placed in cardboard-boxes, which are produced earlier in a parallel flow. The cardboard-boxes are produced, i.e. folded and glued, in a parallel flow with a buffer of approximately 25 boxes waiting to be filled.

Further, the cardboard-boxes containing the products are labelled (*labelling process*) and placed on a pallet of either 12 or 16 cardboard-boxes, depending on the packaging size and product type. An automatic robot turns the boxes and places them with the label fully displayable before sending them to the next station, which is *plastic wrapping*. The entire pallet is then wrapped in plastic foil and sent to storage for further transportation. Every day 6 trucks containing 66 pallets are transported to Santa Maria's end customer, which is the common Santa Maria warehouse in Kungsbacka, Sweden. Production process flows visualizing various packaging processes are available in Appendix A, figure 1.

As mentioned earlier, the manual packaging line is used to produce a specific product type for larger orders. During this packaging process, cardboard-boxes with the capacity of 2.7 kg chips, are prepared manually. Further, the correct amount of chips is released into the box. The sealed boxes, containing the finished product, are then placed on pallets and transported manually for delivery.

3. Theoretical Framework

The theoretical framework introduces the different theories and concepts used throughout the project and gives the reader a more comprehensive understanding. Lean production principles are the main focus and the subchapter is divided into two sections discussing the most relevant parts of Lean used in this project. Furthermore, introductions to Discrete Event Simulation and Predetermined Time Systems are given.

3.1 Lean production

Lean production is implemented in different types of companies with the aim of efficiently reducing waste, balancing out the production and improving the overall production quality. It was mainly developed for the automotive industry, but has expanded and is now used worldwide (Liker, 2004). There is more to Lean production than simple and user-friendly tools; there is an entire philosophy of waste identification and elimination beneath the surface, which will be introduced in the next subchapters.

3.1.1 Lean production philosophy

The Lean production philosophy and principles originate from the Japanese automotive industry and its area of use has extended to different types of businesses and industries all over the world. It was first developed and implemented at Toyota Motor Corporation and hence has its roots in the Toyota Production System (TPS) (Liker, 2004).

Lean production consists of different long-term philosophies, techniques and tools that together form a basis for improving the overall production quality in the factory. Despite the advocating of this "ground rule", many companies manage to implement merely a part of Lean production, in hope of obtaining rapidly improved results (Liker, 2004). What these companies do not quite understand is that Lean is not a quick tool for success; it partly includes a long-term philosophy, Lean-thinking and tools that have to permeate the whole company in order to generate improved results (Wänström, *Lean Principles*, 2011). Also, production processes are different; a case example used in a Lean field book or a tool used at Toyota may not be suitable in other environments. There is nothing wrong with having high expectations on achieving rapidly improved results. The problem is that this approach contradicts with most of the Lean philosophical elements that require a long-term view (Liker and Meier, 2006).

The long-term philosophy of Lean production is often illustrated with the Lean temple, figure 2, where customer satisfaction is the top roof and hence is the prior goal of the production. In order to reach this goal, there are several supporting bases that first have to be reached and fulfilled. A good way to explain the Lean temple is that *"…customer focus implies the highest quality, at the lowest cost with the shortest lead time*". (Bengtsson and Johansson, 2008, p.13)

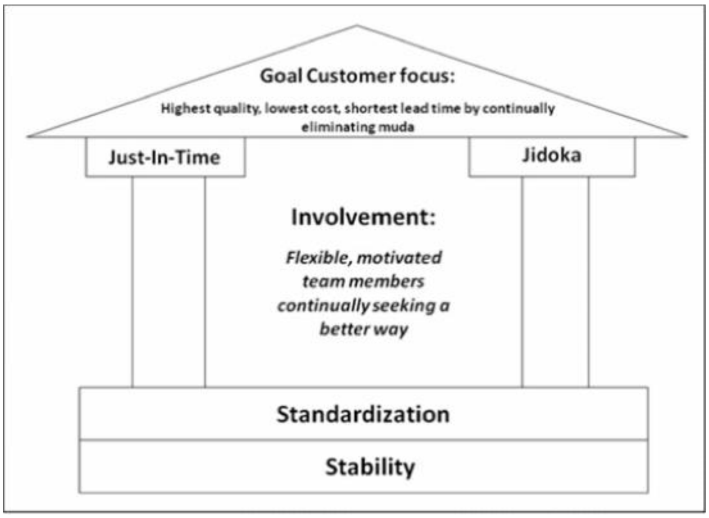

Figure 2: The Lean temple (Liker, 2004).

The first base of the Lean temple is stability. Improvement in the essence of Lean production means working with small incremental changes continuously rather than introducing radical changes that affect the stability of the production. The Japanese word for continuous improvements used in the context of Lean is *kaizen*. Furthermore, if the production is unstable, bottlenecks and problems will be more difficult to locate. The basis of Lean-thinking is the continuous strive for improvement and always wanting to be superior – in the eyes of the customers and the employees. If a company settles and stop striving towards this never fulfilling goal, it will lose its competitiveness and attractiveness and hence be unsuccessful (Wänström, *Lean Principles*, 2011).

Standardization is the second base of the Lean temple. When the production is stabilized, bottlenecks in the production need to be addressed. To be able to localize bottlenecks, problems have to be brought up to the surface. The Lean production approach to this is standardizing the procedures in order to distinguish the deviations (Liker, 2004).

The right supporting base symbolizes Just-In-Time (JIT) production. Just-In-Time is an ideal production process where a specific amount of products are produced with the correct amount of materials needed, in the right time and at the correct place. JIT is mainly used to reduce the inventory and costs for products in process, increase the production efficiency and product quality. The left supporting base symbolizes *jidoka*, which stands for visualizing problems. The principle of jidoka is building in quality during the manufacturing processes. This means that defected products are detected early and are either instantly discarded or repaired, which means that defected products are never sent to the next process (Liker, 2004).

Fulfilment of the requirements of the first bases of the Lean temple is achieved by using various Lean principles and tools. Further accomplishments in turn lead to the top roof of the Lean temple, which visualizes customer satisfaction (Liker, 2004).

Waste identification
One of the main building blocks of Lean production is reducing or eliminating unnecessary waste that slows down the production. The Japanese word for waste is *muda*; waste is defined as the non-value adding activities of the production. To eliminate waste, processes have to be observed and value-adding activities, that create value for the customer, must be distinguished from non-value adding activities (Liker, 2004). Through a Lean production perspective, there are eight different types of wastes.

According to Liker, (2004) the eight mentioned wastes are:

- **Overproduction:** Producing goods for storage that are not ordered by customers. This type of waste does the most damage since it causes all other wastes in the long run. Producing goods for storage without considering customer demand creates waste such as excess inventory and overstaffing.
- **Waiting:** Waiting in general, e.g. workers waiting for a process to finish, for material or waiting to interfere when needed.
- **Unnecessary transports or conveyance:** Transportation of materials, parts or finished items between processes or into/out of storage. Moving Work in Progress (WIP) shorter or longer distances.
- **Overprocessing or incorrect processing:** Inefficiently designed tools or products, requiring unnecessary process steps to finish parts. Inefficient processing causes unnecessary motion and produces defects. Also, producing items of higher quality than necessary generates waste.
- **Excess inventory:** Excess inventory of all kinds; raw material, WIP, finished items, causes long lead-times, obsolescence, damaged items, transportation and storage costs. Also, excess inventory can hide problems such as production imbalance, supplier problems, defects, equipment downtime, and long setup times.
- **Unnecessary movement:** Any kind of non-value adding employee movement during work; walking in general, searching for or reaching for tools.
- **Defects:** The production of and mostly the wasteful handling of defective items; correction, repair, rework, scrap, and inspection are all considered very wasteful along the production. It is time and effort consuming and should be avoided as much as possible. To produce fewer defects and hence increase quality, inspection should be a part of every production unit.
- **Unused employee creativity:** By not engaging and listening to the employees, the company loses valuable ideas, skills improvements and learning opportunities.

The essential waste that mainly needs to be considered is overproducing products, since it results in a chain of other types of wastes. It is worth mentioning again that producing items that are not required by the customers results in excess inventory and hides other types of problems. The first seven wastes also have an impact on the eighth waste. Waste in general, such as overproducing and excess inventory, tends to hide problems, which in other terms means that the employees are not forced to think. Reducing waste hence exposes problems and forces employees to use their creativity for problem solving (Liker and Meier, 2006).

3.1.2 Waste elimination

Improvement work in the essence of Lean production is a continuous process of eliminating the eight types of wastes introduced in the previous chapter. This chapter is more focused on different suitable Lean-thinking methods and tools used for reducing waste throughout project. The appliance of Lean production at Santa Maria is then discussed in the analysis part.

Standardized Work

As mentioned earlier very briefly, standardizing work is one of the crucial parts of the Lean production philosophy. By standardizing production processes and work methods, problems can be brought up to the surface and hence facilitate the problem analysis. Also, standardization provides a simplified way of distinguishing the deviations (Liker, 2004).

The word *standardization* is often misinterpreted for coercive bureaucracy and rigidity, and many believe that standardizing work prevents creativity, individual expression, and growth at the workplace. In fact, standardizing is the exact opposite. Firstly, if production processes are unstable and unrepeatable it is more difficult to predict the timing and the outcome of the process. Also, each operator tends to create his/her own way of working, which means that several work procedures have to be reviewed and improved. Secondly, by reviewing and combining the different work methods, one “best practice” up to that point can be developed (Liker and Meier, 2006).

The standardization does not mean that this best practice cannot be changed; the purpose of standardization is to continuously improve it using the creativity of the users. The changes are then incorporated into a new standard. Without this standardizing process, individuals may make great improvements in their own way of working with the following related problem that no one else can be a part of it – except through spontaneous discussions. Standards provide a starting point for accurate and permanent innovation (Liker and Meier, 2006).

Developing standards

Standardization is not a tool that can be used in a certain phase of a Lean transformation. Another more correct way of interpreting standardization is *"…creating the best possible work method, with the least amount of waste, producing the best quality products at the lowest cost".* (Liker and Meier, 2006, p.113).

Standardization is the necessary baseline for working with kaizen, which is the Japanese word for continuous improvement. The development of standardized work tasks is hence one of the first fundamentals of implementing Lean production and has to be considered throughout the whole Lean transformation. The creation of standardized work processes includes reviewing, defining, and clarifying different methods that can further be compiled into one best practice that at that moment generates the best outcomes, figure 3 (Liker and Meier, 2006).

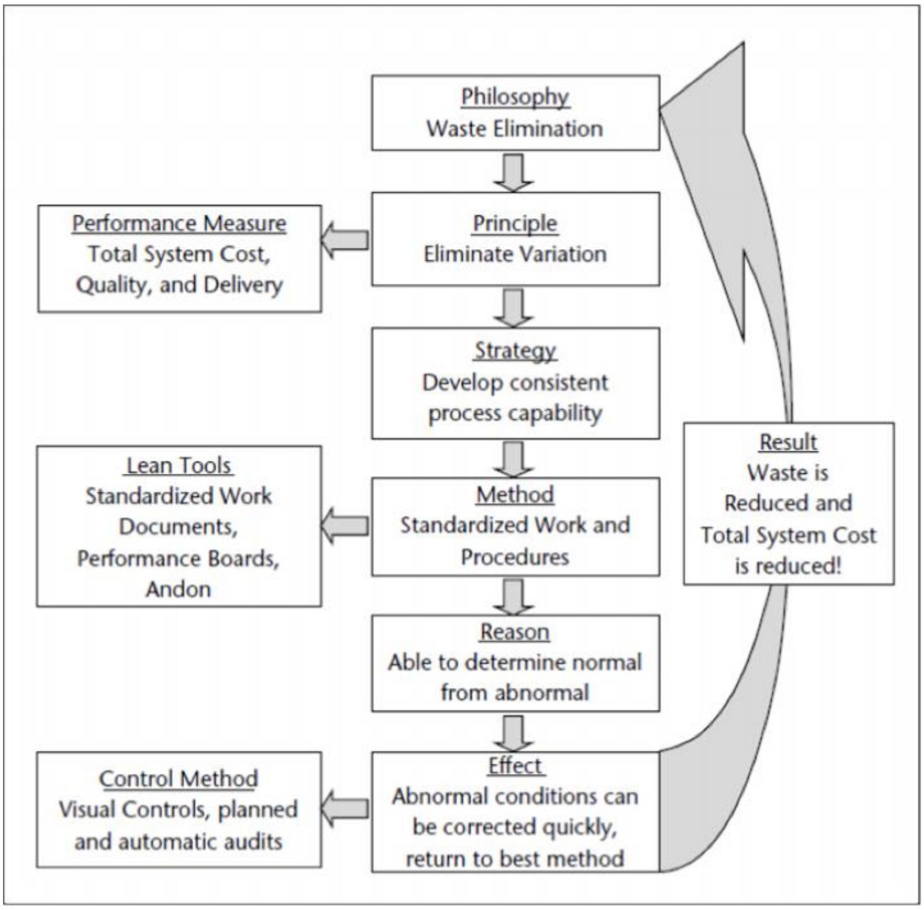

Figure 3: The benefits of Lean waste reduction at work (Liker and Meier, 2006).

Waste elimination can only be obtained if variations within processes are reduced; variation is the exact opposite of standardization. Many different Lean tools can be used for standardizing; the most commonly used tool is standardized work documents and visual control methods such as performance boards. Another part of standardization is training co-workers to be multi-skilled. Standardized work processes require filled work position at all times, which means that a lot of focus must be placed on job instructions and training in order to acquire highly multi-skilled associates (Liker and Meier, 2006).

It is worth mentioning that standards should not be created by the management for workers to use – standards should be created together *with* the workers *for* them to use. Operators who perform the work tasks daily have expertise knowledge about the work and will make significant contributions to the standardization (Liker and Meier, 2006).

Pull and push systems

Avoiding overproduction and eliminating inventories are two of the main principles included in the Lean production philosophy. According to Taiichi Ohno, a production manager at Toyota who is often referred to as the founder of TPS, excess inventories results in more unnecessary products and related storage costs. The key concept behind an effective production is not to manage inventory – it is about eliminating it (Liker, 2004).

Pulling inventory in the production system, based on the actual customer demand, is the main concept of *pull system*. This type of system is based on resources in progress ordering the necessary items from the previous resource in the production chain, and makes it possible to eliminate inventories as much as possible, figure 4. One-piece flow is the ideal pull system state, meaning that only one item flows through different production steps. In a one-piece flow, there are no existing inventories and the production is only customer dependent. The pull system reduces waste by eliminating the amount of storage space needed for inventory and the costs of storing items (Liker, 2004).

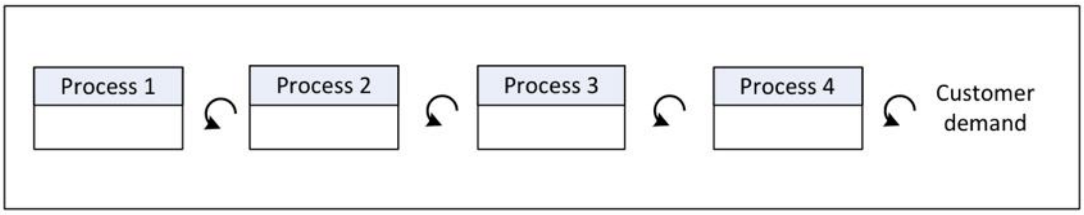

Figure 4: Pull system where the order "pulls" through the delivery path.

Unlike the pull strategy, the push production system is based on unanticipated customer demand. Goods and raw material are pushed forward in the production flow between different resources based on earlier sale forecasts, figure 5. A significant disadvantage with a push system is that inaccurate forecasts from previous years result in stored items both during and after the production (Liker, 2004).

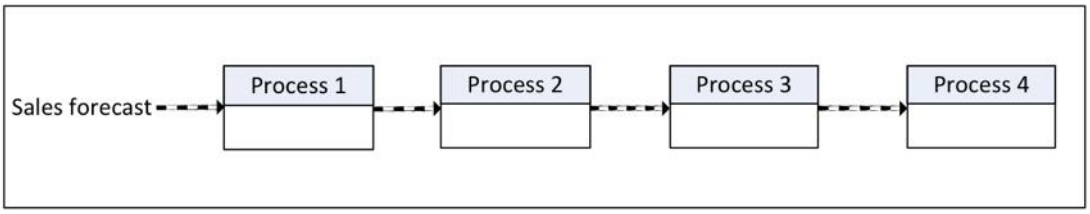

Figure 5: Push system where decisions are based on long-term forecasts.

It is worth mentioning that both pull and push systems can be applied to the whole supply chain of a company, where both strategies can be used for handling goods as well as information (Liker, 2004).

By reviewing the production flow, from raw material to finished products, various hidden problems regarding the production pattern and inventories can be exposed. Generally, through a Lean perspective it is more helpful to start reviewing the production in the reversed direction; from finished products to raw material. By doing this, the production flow is seen through the customer's perspective and hence points out the value-adding work. The customer does not want to know where material is going next; the interesting part is where the material is coming from – is it being *pushed* through the production whether it is requested or not, or is it being *pulled* from the earlier processes? (Liker and Meier, 2006)

By reviewing the production flow and considering the push and pull philosophy, a *Value Stream Map* of the production can be created for further improvement work. Value Stream Mapping is introduced thoroughly in the following chapter.

Value Stream Mapping – VSM

Value Stream Mapping is a visual tool developed within Lean production with the aim of visualizing the material and information flow throughout all value-adding processes. It is widely used in the industry and serves as a baseline for improvement. By mapping the current state production, the production lead-time can be estimated as well as the value-adding work of the production lead-time (Liker, 2004).

By producing and evaluating a current state map of the production, hidden problems can be brought up to the surface and be easily identified (Liker, 2004). When a process is reviewed and modelled as a timeline of activities, material, and information flows, unfortunately a larger amount of waste than value-adding activities is usually found. Locating the waste is not the same as eliminating it; the challenge is to develop a systematic method for continuous waste identification and elimination (Liker and Meier, 2006).

All value-adding production processes are modelled on one piece of paper, together with associated data such as cycle times and number of resources. Some basic process data is previously known but further data requires empirical gathering and may hence be time consuming. Many companies spend a lot of time and effort in the current state phase trying to construct a "correct" map. In fact, the purpose of mapping is to notice that things are far from right and that every production is far from ideal (Liker and Meier, 2006). When it comes to the information flow, it often requires interviewing purchasing managers or similar employees. There are different objects symbolizing the interactions between the processes, e.g. dashed arrows symbolize push flows and triangles symbolize buffers; the symbols are all presented in Appendix 2, table 1 (The Northwest Lean Networks, 2012). A general example of a Value Steam Map is presented in figure 6.

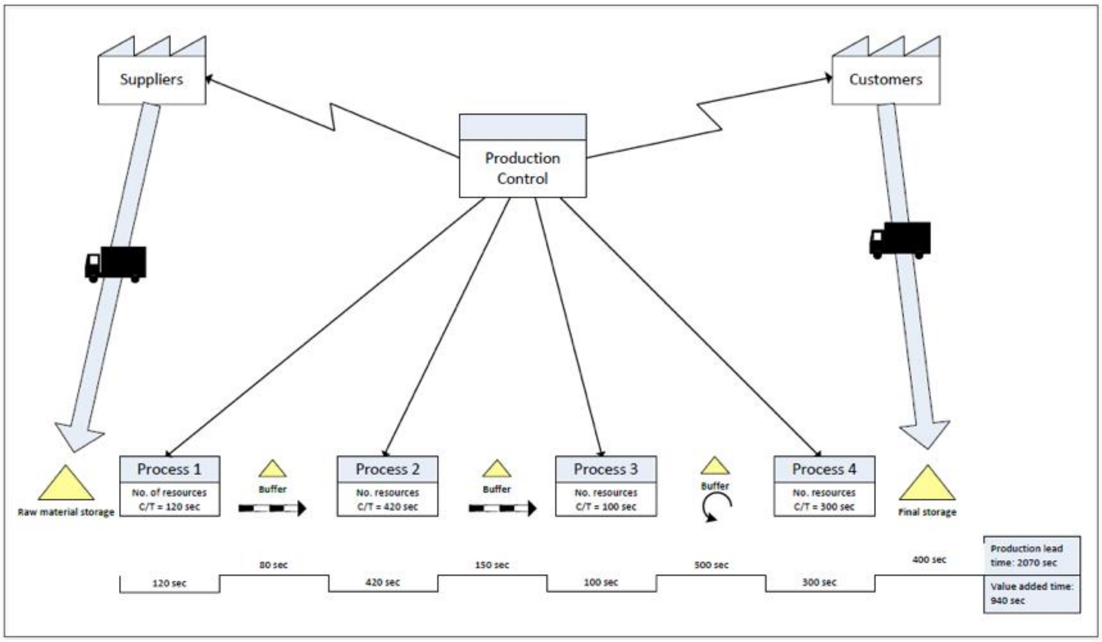

Figure 6: Example of a Value Stream Map.

The next step is to create an improved future state map; the aim is often to shorten the lead-time and the non-value adding time. The future state map should be developed after consultation with all involved parties, such as production units, production managers and the overall management. This will provide a thorough and common understanding of the current state, which will facilitate the compilation of improvements and the development of the future state map (Liker, 2004).

The current Value Stream Map is not the essential part of working with VSM. It is rather the future state map that serves as an eminent baseline for the implementation of possible improvements, based on the problems revealed by the current state map. The future state map represents the model of the goal that needs to be achieved (Liker and Meier, 2006).

Value Stream Mapping is more than modelling the plant with the aim of reducing waste; this is only one of the benefits. It visualizes the mechanism of the production, the chains of processes; an understanding of the overall flow is required before inspecting specific processes. Hence, the aim of improving various processes is to achieve a more balanced flow. The map should be used as a guideline and the details should be developed through time. The simplicity of mapping the production also provides a common language and understanding for the involved parties (Liker and Meier, 2006).

Single-Minute Exchange of Die – SMED

Single-Minute Exchange of Die (SMED) is one of the main methods used in Lean production with the aim of reducing changeover times. By reducing setup times increased productivity can be achieved, which in turn results in increased product output and less man-hours (Almström, *Setup time reduction,* 2011).

The phrase *single minute*, which is a part of the method's name, does not imply that all changeovers should take only one minute. Setup times should in general take less than ten minutes; in other words single-digit minutes are of interest (Shingo, 1989).

All operations during a setup can be divided into two main categories; external and internal setups. External setup tasks refer to tasks that can be performed while the machine is producing. On the contrary, internal setup tasks can only be performed when the machine is not producing (Almström, *Setup time reduction,* 2010).

Separating internal operations from external operations is a fundamental part of the technique applied in SMED. The intention during the appliance of SMED is to convert as many internal tasks as possible into external operations, which in turn results in shorter production downtimes (Almström, *Setup time reduction,* 2010).

3.2 Hierarchical Task Analysis – HTA

Hierarchical Task Analysis is a systematic method used for analysing how a specific work task or material usage is carried out. The method involves a top down structure with the main goal as the starting point. By dividing the main goal into required tasks and sub operations, a hierarchical tree is created. All defined subtasks will further be thoroughly analysed into operations (Berlin, *Manual Work Load Analysis Methods Part 2,* 2011). A general structure of a HTA is presented in figure 7.

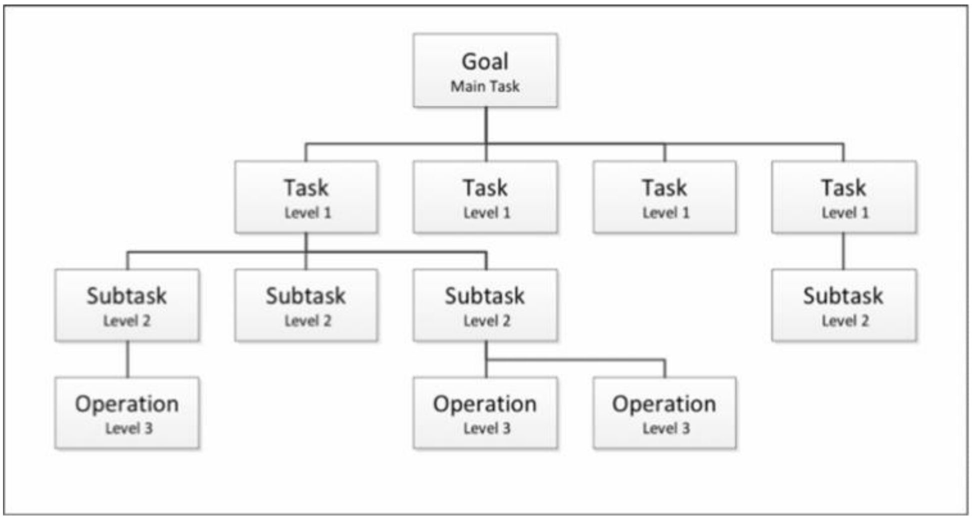

Figure 7: General structure of a Hierarchical Task Analysis (HTA).

Hierarchical Task Analysis is a useful method for gathering information during the earlier phases of an analysis. A main advantage with HTA worth mentioning is the simplicity to adopt it to the purpose of the analysis. The level of detail may be adapted to the actual situation mainly based on the purpose of the analysis (Embery, 2000).

3.3 Discrete Event Simulation – DES

Discrete Event Simulation (DES) can be defined as the depiction of a regular process or system over time for experimentation and evaluation purposes. By simulating a present dynamic process, it is encoded and modelled in a virtual environment for observation. The definition of the word *discrete* indicates that the variables that are described are unrelated, and an *event* is often defined as an interesting occurrence. Discrete event models include time-based jumping activities between different events. The system calculates a new state when a new event occurs (Johansson, *Theoretical basics of Discrete Event Simulation*, 2010).

3.3.1 The application of simulation in production processes

The increasing demand for products of higher quality, shorter lead-times and reduced production costs have forced manufacturing companies to employ other concepts and changes than the conventional to gain efficiency. The main reason of the greater employment of simulation is to solve real-world problems occurring in factories without implementation or having to interfere with the present production (Huda and Chung, 2002). Simulation modelling enables a virtual analysis of locating bottlenecks and evaluating resource interactions. Solutions can be tested in the virtual environment, only costing the company knowledge and time. Depending on the results obtained by a simulation process, the solutions can either be implemented in real life or deselected due to the disadvantages and hence save the company both effort and money (Johansson, *Theoretical basics of Discrete Event Simulation*, 2010).

By using DES techniques, a lot of possibilities and constraints of the production can be explored. It brings the problems up to the surface and provides a greater understanding of why they occur in the first place. The simulation technique tends to change and improve the developing process. The outcome of a simulation model is a solution based on the interactions of the system components. It provides a verification of the integration between product and production process. The lead-time can be reduced continuously and there is less need for costly prototypes (Johansson, *Theoretical basics of Discrete Event Simulation*, 2010).

The benefits of simulation are many; as mentioned earlier it is a good aid in the decision making process, since it highlights the correct choices. Also, by simulating first, the company can make wiser investments. For example, it is not necessary to invest in new costly equipment or solutions unless they generate good results based on the simulation. A drawback is that it is time consuming; this is mostly evident in the data gathering and the coding processes. Another drawback is bad input data based on rough estimations and assumptions that may produce misleading outputs (Johansson, *Theoretical basics of Discrete Event Simulation*, 2010).

3.3.2 Other areas of application

Discrete Event Simulation is an essential engineering approach used in modern manufacturing due to the advantages presented earlier. It is also a widely used tool in the field of logistics, transportation and distribution. It can be used to evaluate rout planning or simulating sorting strategies in distribution centres. Another application is infrastructural planning; handling queue problems in hospitals, airports, with public transport and motor traffic in urban environments. A further application of simulation regards strategic workforce planning in business centres. Other business processes such as customer flows may be evaluated in banks, restaurants and other business centres. Simulation can also be used in the military to model areas of interest to gain knowledge and understanding for strategic purposes on how to act in reality (Johansson, *Theoretical basics of Discrete Event Simulation*, 2010).

3.4 Predetermined Time Systems – PTS

Standard data have been used since the late 19^{th} century, in conjunction with the development of Fredrick W. Taylor's *Scientific Management*, also known as *Taylorism* (12 Manage, 2012). Standard data are elemental times generated from different time studies conducted at that time for later use. Often, an ideally skilled operator was observed and each operation's time was estimated, indexed and tabulated for further use. The main purpose was to be able to estimate the *actual* working time to obtain more efficient work in the factories (Freivalds, 2009). The standard times were supposed to reduce both slackness and excessive ambition during work. Taylorism is often associated with rigidity and exploitation of workers – humans were considered as working machines, which often resulted in injured and unhappy workers. The theoretical idea and intention of Scientific Management was good but in reality it was very easily abused by managers who only wanted to increase productivity (12 Manage, 2012).

Despite its stiffness and drawbacks, Taylorism contributed a lot to efficient production methods and the development of standard times. Standard times are also referred to as *basic motion times*, *synthetic times*, or *predetermined time systems*. Each standard is assigned to original motions or groups of motions that are very difficult to evaluate precisely with traditional time studies (Freivalds, 2009).

"The time values are synthetic in that they are often the result of logical combinations of therbligs; they are basic in that further refinement is both difficult and impractical; they are predetermined because they are used to predict standard times for new work resulting from methods changes". (Freivalds, 2009, p.499)

Ever since 1945, there has been an increasing interest of using standard times for accurate time studies instead of using the traditional time measurement devices, such as stopwatches. Today there are more than 50 different systems based on predetermined times. These systems mainly consist of motion-time tables with explanatory rules and instructions on how to use the different tables. The various systems are each suitable for different work environments, different work cycle lengths, and vary in the level of detail. The analysis is also time-consuming in different ways depending on the system's level of detail. Worth mentioning is that most companies that develop Predetermined Time Systems often require certification before giving other companies access to their material (Freivalds, 2009).

3.4.1 Methods-Time Measurement – MTM

Methods-Time Measurement (MTM) is a Predetermined Time System developed in 1948 for analysing time studies of manual labour for productivity purposes. The MTM-system is based on the principle that every specifically defined motion has a single associated time value, i.e. a standard time that is determined by the nature of the motion and the surrounding conditions. There are several subsystems of MTM varying in the level of detail, time consumption, and areas of use; MTM-1, MTM-2, MTM-*3, Sequence-Based Activity and Method analysis (SAM)*, MTM-V, MTM-C, MTM-M, etc. (Freivalds, 2009), (Nordisk Produktivitet, 2012).

MTM-1 is the most accurate method and hence requires the longest time to perform. It is mostly used for analysing short work cycles and its data is based on motion picture films (frame-by-frame analysis) of different types of work. The different movements are divided into three different categories; one for arms, hands and fingers, another for body movement, and a third for eye movement. The categories consist of the ground movements *reach*, *move*, *turn*, *grasp*, *position*, *apply pressure*, disengage, release, body movements (leg-foot, horizontal, and vertical), and *eye movement*. The time values are given in the time unit *Time Measurement Unit* (TMU), where 1 TMU corresponds 0.00001 hours or 0.036 seconds.

The ground movements for MTM-1, presented above, are merged together in the subsystem MTM-2, which then contains more complex body movements. This reduces the analysis time drastically, table 1, but the analysis becomes less detailed as well. MTM-2 is mostly suitable for non-repetitive work and for work cycles that are at least one minute long.

Table 1: Different MTM-systems and their estimated analysis time (Laring, *SAM*, 2010), (Virtuell Process och Produktframtagning, 2012).

MTM-system	Required time for analysing task
MTM-1	350 × cycle time
MTM-2	150 × cycle time
MTM-3	35 × cycle time
SAM	30 × cycle time

Generally, the shorter it takes to perform the analysis, the less detailed and accurate results are obtained. Based on the time consumption however, the results do not differ that much in percentage. The percent accuracy for different types of MTM-systems is presented in figure 8. SAM, which is presented more thoroughly in the next chapter, is not included in the comparison of the MTM-systems. SAM is considered as a form of MTM-3 system and its percent accuracy and analysis time is therefore very similar to MTM-3 (Almström, *Predetermined Time Systems*, 2010), figure 8, table 1.

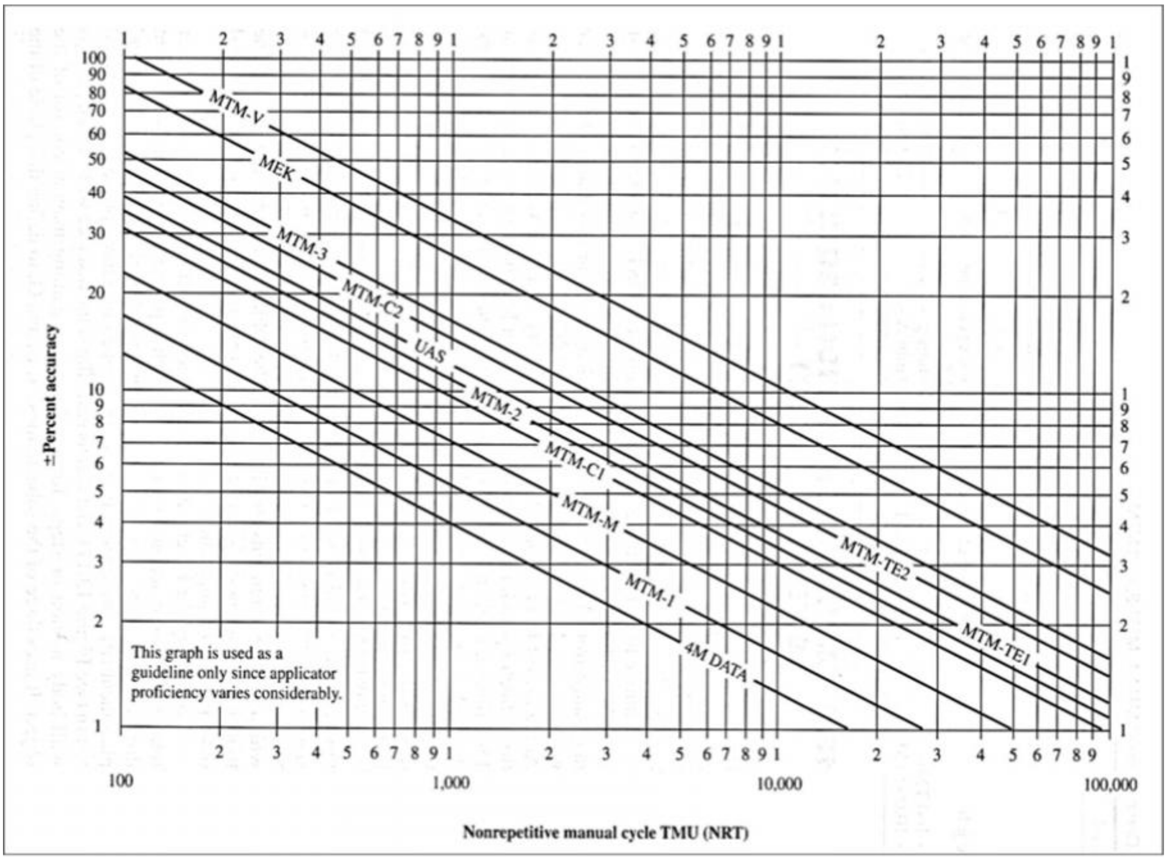

Figure 8: Total absolute accuracy at 90 per cent confidence level of the different MTM-systems (Freivalds, 2009).

Sequence-Based Activity and Method Analysis – SAM

Sequence-Based Activity and Method Analysis (SAM) consists of even more combined movements than MTM-2 for further simplification of the analysis. Once more, the analysis time is reduced drastically at the expense of the level of detail, table 1, figure 8. SAM is used for analysing longer work cycles and many companies use it for estimating the time of the entire production. A SAM-analysis requires knowledge about how the operator moves during work, if the work is repetitive, if it involves heavy workload or requires force, and if precision is needed (Laring, *SAM*, 2010).

The work is divided into three activity categories; *base activities*, *repetitive activities* and *supplementary activities*. Base activities include motions where the operator *GETS* or *PUTS* objects in places. Repetitive activities include screwing, cranking, pushing buttons or reading. Supplementary activities include steps, bending, if any precision is needed and if force is applied. The time values in SAM are given in *factors*; 1 factor corresponds to 0.18 seconds, which in turn corresponds to 5 TMU (Laring, *SAM*, 2010).

The basic activity *GET* is performed to gain control of one or more objects with hands or fingers. The activity begins when the hand or fingers move towards the object in question and ends when the object is grasped. The *GET* activity consists of two variables; how many components that are grasped; one or a handful, and the distance required for the grasping (Laring, *SAM*, 2010). The following distances used in SAM, according to Laring, (2010), are presented in table 2.

Table 2: Distance values in SAM (Laring, *SAM*, 2010).

Distance	Obtained SAM-value
0 cm < distance ≤ 10 cm	10
10 cm < distance ≤ 45 cm	45
45 cm < distance	80 (including a supporting step)

The *PUT* activity is performed when one or more objects are moved to a final position with hands or fingers. The activity begins when the hands or fingers start moving the object in question towards its final position and ends when the object is placed there. This activity includes movement and adjustment of grip, changes in the direction of movement, and the transferring of the object from one side to the other. The distance variable for the *PUT* activity is similar to the *GET* activity, the other variables depend on the weight of the object; higher or lower than 5 kg, and if precision is required (Laring, *SAM*, 2010).

Regarding the supplementary activities, *additional force* is assigned when force must be applied to overcome a resistance during work, and steps are added when the distance is greater than 45 cm. Note that the SAM-value of 80 includes one supporting step, table 2. Bending is applied when the operator is working in a bent condition, or picks up items (Laring, *SAM*, 2010).

Compared to the more detailed MTM-systems, a benefit of SAM is that it is simplified to the level that it is easier to perform and hence does not require a highly skilled analyst that is previously familiar with the system. Also, a complementary function called *ErgoSAM* can be used for detecting ergonomic problems during work. ErgoSAM is based on an *ergonomic cube value*, which is calculated with the variables *time*, *work posture*, and *weight*. For example, an operator working in a *good* work posture, for a *long time,* carrying heavy *weight* can generate the same ergonomic cube value as an operator working in a *bad* work posture, for a *short* time, not carrying any weight. It takes approximately 5% longer time to perform this additional analysis. It is performed by inserting one row for each base activity in the SAM-sheet, used for ergonomic reflection (Laring, *Ergonomics and ErgoSAM*, 2010).

4. Method and Implementation

This chapter includes the different methods used throughout the project to solve the different problems at Santa Maria. The initial approach is a data gathering process required for further analysing. A detailed current state analysis is conducted and based on the obtained results suitable improvement suggestions are presented.

4.1 Data gathering

To be able to identify and reduce different types of wastes in the factory, a review of the entire production is required. A combination of theoretical, practical and empirical approaches is used throughout the different phases of the project. The data gathering process is divided into four main topics; interviews, literature reviews, company data reviews and empirical observations.

4.1.1 Interviews

The project began with data gathering in order to understand the situation and specify the actual problems in focus. Interviewing concerned employees and production managers at Santa Maria were an initial part of the data gathering phase. It is very important to both consider the opinions of the management as well as the shop floor operators, which perform the tasks every day. The latter mentioned might have expertise knowledge that is valuable for the work (Rubenowitz, 2004).

About 20 questions were generated as a baseline for interviewing concerned employees including operators, team leader, production manager and purchaser. Operators of different age, gender, area of responsibility and carrier length were interviewed in order to obtain an overall impression of the existing problems in the production but also to acquire different perspectives. The interviews took approximately 40 minutes to complete and the employees were interviewed individually in separate rooms. The results of the interviews were then compiled, evaluated and analysed. The compilation of all interviews can be found in Appendix C.

4.1.2 Literature reviews

Literature reviews including scientific papers related to the subject, waste elimination and applying Lean principles in the industry were reflected and used for the theoretical framework. Also, a short introduction to Discrete Event Simulation was generated for the upcoming analysing phase. Predetermined Time Systems were also considered for later standardization and productivity purposes. The main purpose of the theoretical framework is to trace the different statements made and also to explain the used theories and concepts in a way that a reader who is not familiar with them can comprehend the work.

The structure, contents and references of similar projects and theses have been reflected as well.

4.1.3 Company data reviews

Data from different kinds of evaluation systems at Santa Maria was used to develop an understanding of the current production state. Several vital production data and 3D-drawings of the production were provided by Santa Maria and facilitated the analysing phase of the project.

The production data included input parameters from 2011 such as production outputs, amount of waste and statistical parameters of total number of breakdowns for individual resources. Further data included e.g. the amount of ingredients necessary to produce a predestined quantity of chips together with cost estimations.

The production data was particularly supportive in the analysing phase of the project. For the DES-simulation process, further data had to be collected to complete the simulation model.

4.1.4 Empirical observations

In addition to the previously mentioned methods, practical and empirical studies at Santa Maria have been conducted for the data gathering process.

Several company visits were made with the purpose of collecting and calculating important data that was mainly needed for the simulation model. The empirical observations mostly consisted of reviewing cycle times for all machines as well as estimating the buffer capacities between the processes. In some cases it was merely impossible to measure parameters and hence estimations based on the groups engineering skills were necessary.

An irregularly shaped object, e.g. in form of a larger taco shell, was sometimes inserted and followed in the processes to be able to distinguish it from the hundreds of surrounding chips. This facilitated the reviews of cycle times.

4.2 Application and analysing

To specify problems in focus and to analyse the current state of the production process, different theoretical tools such as Value Stream Mapping (VSM), Hierarchical Task Analysis (HTA) and other relevant tools were used. Technical experiences both from the leadership and workers were considered during this phase.

4.2.1 Production process flow

In order to obtain more comprehensive and detailed knowledge about the production in general, process flows were developed. These flows are earlier described in chapter 2.

The production at Santa Maria was reviewed carefully several times, which allowed a detailed mapping of the production. Two process flows were developed for each of the two product types, i.e. chips bags of 200 g or 500 g, since they are produced in different lines and are packed differently. The process flows include buffers and various raw materials, which visualizes the transformation of raw material to finished products. The results of this part of the project have been very accommodating for further analysing, mainly for the simulation phase. The process flows are available in Appendix A, figure 2 and figure 3.

4.2.2 Analysis of Value Stream Mapping

To be able to perform an analysis, a thorough initial analysis of the current state at Santa Maria is necessary. The current state analysis is conducted and divided between the two main sections; manufacturing and packaging section. The discussed topics are the different processes, their current related properties and problems, and the operator involvement.

Manufacturing section

To start with, Santa Maria stores raw material needed for the manufacturing and packaging of their products. The stored amount is based on the usage and it is controlled by a production planner that keeps track of the raw material consumption and places orders. The following subchapters discuss the different processes of the manufacturing section in detail followed by their possibly associated problems.

Mixing process

The chips manufacturing is as mentioned earlier initiated by a mixing process that mixes together the ingredients of the product; salt, water and cornflour. The mixed ingredients are further processed into dough in 2 parallel mixing chambers that carry 215 kilos of dough each. The mixing process takes 6 minutes to perform before the dough is passed on to the second chamber. The second mixing chamber can be considered as a buffer that stores the mixed dough and passes amounts of it on to the rolling operation.

Rolling and forming process

Immediately after the mixing operation, the dough is passed on to a *rolling operation* where it is rolled into thinner layers and is therefore prepared for the subsequent *forming process*. The rolling operation is carried out by pressing the dough between two rolling wheels, which create the possibility to set predetermined thickness on the dough layer.

It is worth mentioning that all dough of 215 kilos cannot be rolled at the same time, therefore a smaller amount of dough moves through the rolling wheel and is immediately passed on to the subsequent forming process for forming. It is difficult to estimate the amount of dough that is processed and formed, however the total time the dough spends in the chamber, or buffer, is the same as the processing time, i.e. 6 minutes for the rolling of 215 kilos of dough. It has been observed that due to the design of the equipment, dough falls down on the floor due to a significant height difference between the chambers and the rolling wheel, which creates waste in the form of dough. Operators are occasionally needed for cleaning up this waste.

The rolled dough is formed into its final shape during the subsequent forming operation. The thin dough is then passed below a forming wheel consisting of differently shaped knives, which cuts out the final shaped chips. A few optional shapes are available and can be installed in the forming equipment; triangular, which are the most common ones, circular and rectangular. The forming wheel today forms 44 chips during each rotation; this corresponds to 11 chips per row and 4 rows in total during each rotation. However, it is observed that the forming wheel has the capacity of forming 13 chips per row, but only 11 knives are used. Also, the wheel runs with constant speed, i.e. the amount of chips is today not controlled. Since the chips are cut out, the remaining dough is automatically returned to the forming operation and can be reused.

Baking process

The now formed chips are transported on a conveyor belt into the oven for the baking process. The oven consists of three parallel conveyors that all chips pass through during the baking process that takes approximately 20.35 seconds. It was mentioned earlier that the chips exiting the oven are not entirely finished; the texture is somewhat crispier on the outside than on the inside and needs to be evened out. This results in a subsequent operation, the air-drying process. Another conveyor belt transports the baked chips to this subsequent operation. The air-drying process consists of five parallel conveyors that today run with constant speed. The air-drying operation takes about 213 seconds and after that the chips obtain a uniform texture. The design of the air-drying equipment causes amounts of chips to fall off the belt and hence also contribute to the waste. Trash bins are placed intentionally to receive the amount of chips that falls off the belt and need to be emptied by operators occasionally.

Frying process

The crispy chips are further transported on a conveyor belt to the frying process. The chips are lowered into an oil bath and the capacity of the fryer is estimated to the same capacity as the air-drying equipment, approximately 8550 chips. The whole frying procedure takes about 137 seconds and then the chips are transported to a flavouring station on a further conveyor belt that runs with constant speed.

Regarding arising problems concerning the baking and frying processes, chips occasionally get jammed and pile up in the oven and may cause problems such as burned products that need to be cleaned, or fires. Also, the heated oil in the fryer creates a great fire risk. These two processes are often controlled by operators to prevent damage and reduce the associated risks. In case problems arise with these two processes, the whole production needs to be stopped immediately.

Flavouring process

The chips are further transported with an elevating conveyor belt up to a platform where the flavouring process occurs in three parallel flows. This creates the possibility of producing different product types in parallel. The variation between the product types can differ in packaging size and the type of flavour added to the chips. A detailed overview of the chips manufacturing section is available in Appendix A, table 1.

The third flow is not used to a great extent due to limited customer demand. The flavour needs to occasionally be refilled; operators are signalled with lighting equipment when this occurs. The work operations include lifting several flavour bags, which can be considered as heavy workload. Due to the design of the equipment, lots of flavour end up on the floor and contribute to another type of material waste. On the other hand, only material waste, in the form of chips, is considered in this project.

All the mentioned conveyor belts that transport the chips between the processes can be considered as buffers that store products. It is vital to mention that estimating buffer sizes is very difficult due to the properties of the products. These estimations can be viewed in Appendix G and are based on the project group's knowledge and experience. However, it is observed that all mentioned conveyor belts, or buffers, are run with constant speed, which means that approximately the same amount of chips is transported. The conveyor belts are less utilized regarding their maximum capacity; there are height differences that can be used to store further chips by simply controlling the speed of the conveyor belts.

The following subchapter discusses the different processes of the packaging section in detail followed by their possibly associated problems.

Packaging section

The major amount of chips is discarded between the manufacturing section and the packaging section. The occurrences of breakdowns and non-standardized manual operations are the main causes, resulting in the large amount of chips discarded into trash bins. It is confirmed that the later products are discarded during production, the higher the associated costs will be. Stops during the packaging section are difficult to avoid completely due to the highly deviating problems that usually arise and the occurrences of manual operations.

The packaging section consists of all processes that are a part of the packaging and wrapping of the products before delivery to the customer. There are two different automated lines producing different packaging sizes, 200 g and 500 g, and product types. Further, there is a manual packaging line used to produce a specific product package, see Appendix A, figure 1.

Sealing process

As mentioned earlier, the two automated packaging lines have similar layouts and processes, starting with a sealing process. During this initiating operation, a predestined amount of chips is released into a plastic bag, which is cut and sealed. The sealing equipment belonging to packaging line 1, which produces bags á 500g, has the maximum capacity of producing 30 bags per minute. Similarly, the maximum capacity regarding the sealing machine in packaging line 2 is limited to 80 bags per minute. Far from all sealed chips bags end up on a product pallet delivered to the final customer; a great amount of chips is discarded due to several known and unknown problems.

A common error is that the wrong amount of chips is released during the sealing operation. This in turn produces chips bags with either excessive or insufficient content that moves forward to the controlling station. The usage of imprecise internal scaling equipment during the sealing process is the main reason for the occurrence of this problem. An additional problem faced during the sealing operation is that chips bags are not sealed with proper air pressure and accuracy, which results in further problems in the subsequent processes.

The plastic foils used during the sealing operation contain information about the content and are delivered in large rolls of different amount of bags depending on the packaging type and size. The frequency of changing foil rolls depends on the production pace; each roll has a capacity of 5280 chips bags (200 g) and 3411 chips bags (500 g). Foil rolls need to be changed manually, the packaging section is stopped automatically when the plastic foil roll runs out and signals to the operator that it needs to be changed. Change of foil rolls also contribute to discarded chips bags in both packaging lines. Each time a foil roll is changed, a few chips bags must be discarded until the new foil roll is fed through the machine and the production can be resumed. The new foil is attached to the old foil by tape and fed through the machine until the tape is visible.

Lack of standardized work descriptions regarding replacement of foil rolls contributes to unorganised work operations. This results in that the packaging line needs to be stopped during longer periods of time depending on the operator’s skills. More detailed work descriptions including standardized work methods are conducted in following subchapters.

As mentioned earlier, the manual packaging line is used to produce a specific product type for larger orders. During this packaging process, cardboard-boxes with the capacity of 2.7 kg chips, are folded and prepared manually. Further, the correct amount of chips is released into the box. The sealed boxes, containing the finished product, are then placed on pallets and transported manually for delivery. Similarly as the other manual operations, the manual packaging is in lack of standardized work descriptions, which in turn contributes to problems. More detailed descriptions including standardized work methods are conducted in following subchapters.

Controlling process

The sealed chips bags move one at a time to a controlling process consisting of a metal detector, weight and air-pressure controller, where they are inspected. The metal detector discards the bags containing metal parts; these might be machine parts that accidently end up in the production process. If the weight is less than it should be, the bag is discarded. Similarly, if the air pressure differs from what it should be, i.e. is too high or too low, the bag is also discarded. This is due to the product quality assurance; if the air pressure is too low the chips will be smashed during packaging and transportation, and if it’s too high the bag will instead crack open. It takes 2.3 seconds for each bag to pass through the controlling process.

Chips bags with different types of quality problems are detected during this inspection and are automatically discarded into a trash bin. It is worth mentioning that the majority of all discarded bags are caused by improper air pressure. The concerned operator has the responsibility of emptying the trash bin when necessary. The trash container, where all waste bins are tipped, is located relatively far away from the production line, which makes the emptying operation time consuming.

Packaging process

The approved chip bags are transported on a conveyor to the packaging process. The smaller variant of the chips bags are sorted in a predestined number and placed in cardboard-boxes, which in turn are folded and glued around the chips bags. The refilling of glue, cardboard-boxes and resolving of possible arising problems are the responsibilities of the concerned operator. The smaller cardboard-boxes contain 15 chips bags of 200 g.

The packaging equipment operating the smaller chips bags is one of the most troubled resources of the entire production line. A huge amount of chips bags are discarded during this process due to lacking technical equipment design. In addition to discarded chip bags, these problems tend to cause stops in the packaging section and hence requires the involvement of operators. Most of the solutions include the operator making small adjustments and cleaning the equipment from damaged chips bags. The occurrences of errors can in the worst case cause total product waste; complete boxes of chips are occasionally smashed in the equipment, which means that whole boxes containing chips bags have to be discarded. The supplier of this packaging machine has gone bankrupt and cannot provide Santa Maria with technical service and advancement. This situation has resulted in that Santa Maria drives various improvement projects with the aim of making the equipment more reliable.

When it comes to the larger variant of the chips bags, these are directly placed in cardboard-boxes, which are produced earlier in a parallel flow. The larger cardboard-boxes contain 12 chips bags of 500 g. The cardboard-boxes are produced, i.e. folded and glued, in a parallel flow with a buffer of approximately 25 boxes waiting to be filled. Unlike the previously described packaging equipment, this packaging line is significantly more efficient. This equipment is only a few years old and it is not utilized with its maximum capacity, due to a lower customer demand.

Similarly as the first described packaging line, one operator is responsible for refilling of glue, cardboard-boxes and eventually resolving possible arising problems. The parallel flow, which produces cardboard-boxes, is located in a separate passage; it requires that the operator have to walk around a large part of the facility to reach this resource. The main reason that this equipment is placed in a separate location is the limited production area. This positioning in turn contributes to an unnecessary long buffer of 25 finished boxes waiting to be filled with products.

Palleting process
All finished chips boxes containing the final products to the customer are then labelled and transported forward to a palleting process. Further, the cardboard-boxes containing the products are placed on a pallet of either 12 or 16 cardboard-boxes, depending on the packaging size and product type. An automatic robot turns the boxes and places them with the label fully displayable before sending them to the next station. The palleting process is mainly automated, where the only manual operation is to feed the equipment with empty pallets. Refilling of empty pallets occurs rather frequently due to the maximum acceptable number of pallets. It is only allowed to place 15 pallets at height due to work environment security aspects. Also, there is only one single pallet buffer to both packaging lines; this results in that the manual refilling operation is shared between two operators. If necessary, the team leader or an external truck driver may support the operators with refilling of pallets. It is worth mentioning that the operator must hold truck license to perform this operation.

Wrapping process
Further, all finished pallets are transported to the final process, which is plastic wrapping. The entire pallet is then wrapped in plastic foil and sent to storage for further transportation. Both packaging lines are incorporated into one single line that passes through this final process. The plastic wrapping equipment can handle all types of product pallets. Occurrences of technical problems associated with this fully automated station are low. An external truck driver is responsible for both maintenance of the equipment and refilling of raw materials in form of plastic rolls.

Every day 6 trucks containing 66 pallets are transported to Santa Maria's end customer, which is the common Santa Maria warehouse in Kungsbacka, Sweden.

Analysis of production flow with Value Stream Mapping
The previously conducted current state analysis is used to further analyse the situation at Santa Maria through a Lean perspective. Value stream maps are therefore created based on the current observed production. The purpose of creating a current state map is to visualize the material and information flow throughout all value adding processes to detect possible improvements potential. The current state analysis was initiated by interviewing the concerned employees at the production planning and purchasing department at Santa Maria. The whole interview is available in Appendix C.

Based on the previously created production process flows, the current state production analysis, and the results obtained by the interviews, a current state map of the production could be created. It is worth mentioning that necessary data was collected empirically. By evaluating the current state map with Lean production philosophies, hidden problems could be brought up to the surface and be easily identified. Further, a future state map was created with the aim of shortening the lead-time and the non-value adding time. This map should also represent a model of a future goal that is desirable to achieve. It should be used as a baseline for implementing the possible improvements, based on the problems revealed by the current state map, Appendix D, figure 1.

The main focus during the development of the future state map has been to reduce waste by generating applicable improvements. The waste elimination will in turn result in a more efficient production flow. One of the essential aspects of Lean production is implementing a pull system, which creates the potential of eliminating waste and inventories as much as possible. The pull philosophy can be applied in the packaging section including all its consisting resources, which in turn order chips from the previously baking section.

When a future state map is constructed, focus is often placed on reducing the lead-time and the non-value adding time. Generally, the non-value adding time in the food manufacturing industry is relatively short in relation to the total lead-time, due to various product quality aspects. However, improvement work should include aspects of reducing the lead-time. The future state map is available in Appendix D, figure 4.

Based on previously conducted interviews and analyses, the communication between shop floor and management is perceived as insufficient. This can be resulted by a lacking organizational structure. Information and opinions from the shop floor tend to be ignored and forgotten. Improved communication can contribute to an enriched organizational unity.

4.2.3 Standardization of work stations

Standardization is mentioned earlier as merely a requirement for further improvement work in the essence of Lean production. Without standardized work procedures, each operator works as he or she pleases, which makes it difficult to distinguish deviations and hence improve the current work.

As discussed earlier, the chips manufacturing line at Santa Maria is mostly automated. Initially it was discussed that the entire line was in need of standardized work procedures. Or more specifically, the manual work procedures occurring at the line need to be standardized. The analysis started out by reviewing the whole production line and examining which work tasks and sequences were performed manually. Further, the most repetitive manual workstations were selected, recorded and analysed with the Predetermined Time System SAM for standardization and productivity purposes.

The SAM analysis was initiated by breaking down the work sequences, which in a Lean production context can be divided into external and internal activities. External activities can be performed while the machine is producing while internal activities can only be performed when the production is stopped. Further, each work movement was analysed with the standard times, so called factors, used in SAM. The more physically demanding a work movement is, the higher factor value it obtains. The factors were then summed up into a total value that represents the actual time needed to perform the work. The obtained time values should be used as references for standardization purposes. It is worth mentioning that the work sequence in question should be performed by a normally skilled operator working in a rather normal work pace.

A brief presentation of the selected workstations is given below. Also, associated problems and possible improvements are discussed.

Analysis of selected manual workstations
There are a few manual workstations at the chips manufacturing line, which mostly consists of changeovers between different chips product types. These changeovers include e.g. changing of flavour and plastic foil, cleaning, material handling and managing breakdowns. Also, there is a deviating production process, an entirely manual workstation that consists of manufacturing a specific product package for larger orders.

Manual packaging
The manual workstation is used for manufacturing a specific product package for larger orders. All work is carried out manually by two operators working simultaneously; a cardboard-box is folded, plastic foil is inserted in the box and a certain amount of chips is released into the box, figure 9. Further, the boxes are taped with a tape-gun, placed on a pallet and transported manually for delivery. The release of chips occurs by switching the weighing device between two available modes. The first mode is manual, i.e. the operator switches it on or off depending on the individual work pace. The other mode is automatic and hence controls the work pace. A detailed work description is available in Appendix E, figure 3.

Figure 9: An operator folds a cardboard-box.

Currently, there are no existing documented standard times at the chips manufacturing line that can be used as baselines. Therefore, the company requested a conducted analysis with the aim of developing standardized work tasks and standard times. The workstation was recorded with two skilled operators performing

the work in a rather normal work pace. The SAM-analysis indicates that the obtained standard time corresponds to the real performance time.
An interesting idea was to observe the standard time if the manual mode of the weighing device is eliminated. The standard time for pressing a button can be neglected; hence there will be no drastic changes in the total standard time. On the other hand, an elimination of the manual mode may result in a more stressful and sensitive work situation; the slightest error may cause emergency stops in the production or simply piled up waste. Also, through a productivity point of view it is desirable to use the automatic mode but through an individual development perspective it is more suitable to let the operator set the pace for his/her own work.

Changeovers due to chips variant

The existing chips variants are flavoured with salt, chilli or cheese. When the product variant is changed, two main operations must be performed subsequently; changing plastic foil and changing flavouring type. The changeovers mean stopping the production, or more specifically stopping the packaging section. If the operator does not stop the baking section, the manufacturing of chips proceeds in the same pace and also contributes to the waste. It is worth mentioning that ideal changeover procedures were analysed; i.e. replenishment of material and other types of deviating tasks were neglected.

- **Change of plastic foil**

The plastic foils contain information about the content and are delivered in large rolls of different amount of bags depending on the packaging type and size, figure 10. The frequency of changing foil rolls depends on the production pace. Also, changing of foil occurs when the product variant is changed due to the different content information.

The packaging section is stopped automatically when the plastic foil roll runs out and signals to the operator that it needs to be changed. It is important to consider the remaining bags in process; the new foil is attached to the old foil by tape and fed through the machine until the tape is visible, figure 11. The operator then discards the bags and starts up the production again. A detailed work description is available in Appendix E, figure 1.

Figure 10: Stored foil rolls.

Figure 11: Foil roll mounted in the sealing equipment.

- **Change of flavouring type**

As mentioned earlier, changing flavouring type also includes changing plastic foil. The operator stops the line and walks up to the flavouring platform to change flavour, and the second operation, changing plastic foil, is performed afterwards.

When the plastic foil is changed due to a change of product variant, problematic factors that affect the product quality may arise. The packaging section automatically stops when the foil runs out, which means that chips are still produced in the manufacturing section. Unless the operator stops the manufacturing, products are pushed forward through the production chain and cause additional waste. Another issue is that once the packaging section is started up, there are still remaining chips in process of the old flavour type that may end up in the wrong plastic foil. For example, if there is a change from salt chips to chilli chips, there are remaining salted chips in the production that probably ends up in chilli-foil due to the foil-change. The existing solution is that the operators manually collect and discard the outcoming chips bags once the packaging section is started up. By tasting the chips, the production line can be resumed when the correct flavour is in the correct foil. This is a quality problem and today's solution does not assure the best quality, e.g. the bag may consist of 80% salted chips and 20% chilli chips, and is approved anyway.

To solve this problem, and hence to assure the best quality, the time for running out of the products in progress (run-out time) needs to be considered – it has been measured to 01:21 minutes. Before the plastic foil needs to be changed, the operator has to calculate the number of chips bags that corresponds to the run-out time, in order to switch off the manufacturing section in advance.

Another possible solution is that the operator manually discards the amount of chips bags that corresponds to the run-out time. However, this solution not only contributes to more waste of chips, it also contributes to the waste of finished products, i.e. including plastic foil. This also prevents proper recycling; the different materials should be discarded separately but due to the required time, finished products are discarded instead.

Discussion regarding standardization

The difference between the standard times provided by SAM and the work times in reality was marginal. Based on the project group's knowledge and experience, the largest deviations depend on incorrectly performed work operations due to various reasons, e.g. simultaneous working by two operators instead of one. Also, it was observed that the work pace was rather high, which is a common consequence of observation and recording – operators may feel stressed over being observed and may therefore exaggerate the work performance. Again, it is vital to repeat that these standard times should not be followed strictly; they should merely be used as reference numbers for estimations of the work times.

A part of standardizing work is to make standard sheets that should be published in the factory. The standardization should then be updated and improved occasionally.

Santa Maria has an existing standardizing system called the Standard Operation Procedure (SOP). The analysed work procedures were analysed with SAM with the aim of obtaining standardized work tasks and standard times. The detailed work descriptions, which were developed for each of the analysed workstations with SAM, were then combined into new SOP-standards that are available in Appendix F.

4.2.4 DES of production flow with AutoMod

The simulation process begins with observing and mapping the whole production flow of interest. By mapping the production flow with all processes and buffers, a representative overview of the current production is obtained for future assessment.

Further, the production flow is modelled in a virtual environment – in this project, the software AutoMod™ is used for simulation purposes. AutoMod is used worldwide for simulation of production and logistics systems. The software if designed for detailed analysis of operations and flows. A screenshot of the simulation environment is presented in figure 12. The software is mainly used in manufacturing and material handling systems analysis but its application is expanding towards the business sector as well (AutoMod, 2012).

The processes are created as resources including internal buffers with different properties in the AutoMod software. Critical properties, for individual resources, are defined in the software as cycle times, internal buffers and the availability of the resource during the simulation. It is worth mentioning that operators can be simulated as resources as well. Various resources created during the simulation and their properties are presented in Appendix G, table 1.

Conveyors, which transport raw materials, semi-finished and finished products during the production, are simulated as queues in the software. The most critical property of each queue is its capacity, which is based on the actual amount of available items.

Available materials that move along different processes are simulated as various loads in the AutoMod software. Different loads, all from raw material, semi-finished products to finished items, are simulated. Various loads are converted into new load types during the execution of the simulation. All queues and their properties are presented in Appendix G, table 2.

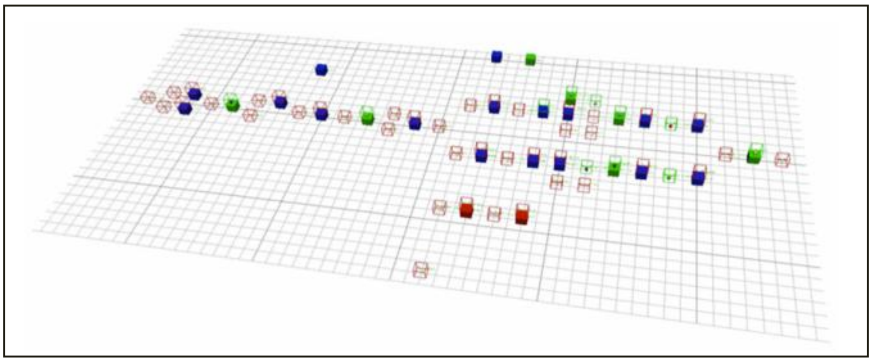

Figure 12: Screenshot of the simulation environment in AutoMod.

Different types of variables in the model control the consumption of raw materials and semi-finished products during the production. Created variables during the simulation and their properties are presented in Appendix G, table 3.

A general overview of all created queues, resources and actual loads is presented in Appendix G, figure 1. The logic behind the program, that controls how the previously mentioned resources, queues and loads collaborate with each other, is created in a source file. The correct data is inserted as parameters in the logic file, i.e. the programming code. The main aim is to get a working virtual model of the present production, which generates real values that correspond to the real-life production. The simulated production model can be analysed in detail executing the model for different runtimes. Further, reviewing reports containing different parameters of created resources, queues or loads completes the analysis. The content of the source file is presented in Appendix H.

All gathered data such as cycle-times, buffer sizes, downtimes and recourse capacities have been collected in the most proper way. Much data of interest is available in the company's earlier documentations, while a lot of data had to be collected empirically. In cases where buffer sizes were not possible to measure, the respective capacity was based on assumptions and statistics. Downtimes for all resources during the simulation are based on the available data from the previous year of production. The available information has been converted into statistical distributions, which in turn were used during the simulation. Calculated downtime-distributions associated to individual resources are presented in Appendix G, table 1.

The data gathering and creation of the logic file is in general the most time consuming part of a simulation process. Assumptions certainly affect the accuracy and vitality of the virtual model and are definitely drawbacks of simulating. The output of the current state model of the production provided by the simulation is presented in table 3. Since the model is partly based on statistically documented data from 2011, it must correspond to the output in reality to serve its purpose as a baseline for improvement work and decision-making. The output of the model relatively agrees with the output of the current production in reality and is therefore considered valid.

Table 3: Current output of finished products during eight hours of production.

	Packaging line 1 (500 g)	Packaging line 2 (200 g)	Total
Produced pallets	61 pallets	79 pallets	140 pallets
Produced boxes	732 boxes	1580 boxes	2312 boxes
Produced bags	8784 bags	23700 bags	32484 bags
Weight	4392 kg	4740 kg	9132 kg
Distribution	44%	56%	100%

After simulation of the present model of the production line the bottlenecks of the system can be located and evaluated. The following step is to implement changes based on engineering skills and calculations.

According to the simulated model, a huge amount of produced chips is discarded daily between various resources. This is due to different types of breakdowns and occurrences of manual work in the packaging section. Figure 13 presents the amount of different types of waste through various steps of the production. An overview including more detailed locations of different waste queues is available in Appendix G, figure 1. It is worth mentioning that the figure below presents the amount of waste created during eight hours of production.

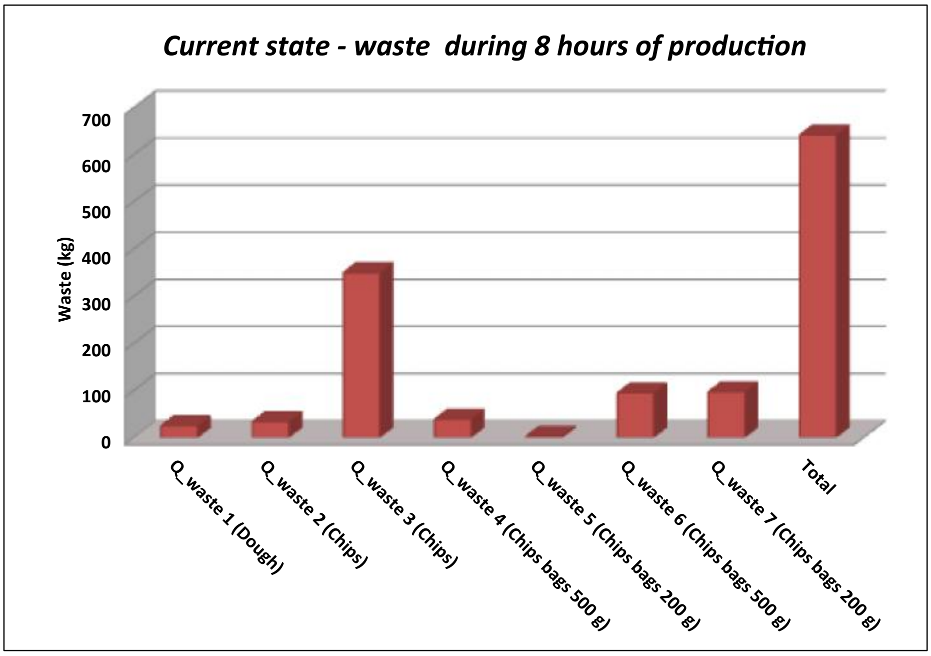

Figure 13: Current state - waste during eight hours of production.

The usage of inadequate rolling and forming equipment is the main reason that some amount of mixed dough is discarded during the production process. The amount of dough is jammed in various types of machine parts, both in fixtures and moving parts, due to the design of the equipment. The large amount of discarded dough ends up on the floor around the equipment and has to be collected, figure 14. The queue representing the discarded dough is named Q_waste 1.

Figure 14: Waste created during the forming process.

The air-drying process also contributes to additional waste due to insufficient design of the transportation conveyor. The baked chips tend to fall off the transportation conveyor, which means that they have to be collected in a trash bin. This trash bin is represented by a queue named Q_waste 2.

The analysed taco chips manufacturing line consists of two main sections; a manufacturing section and a packaging section. Corporation of these two automated sections together produces the final product; see Appendix A, figure 1. The major amount of chips is discarded between the manufacturing section and the packaging section, which can be seen in figure 13. The occurrences of breakdowns and non-standardized manual operations are the main causes, resulting in the large amount of chips discarded in the trash bin named Q_waste 3.

Change of foil rolls also contribute to waste, in the form of chips bags, in the two parallel packaging lines. Each time a foil roll is changed, a few chips bags must be discarded until the new foil roll is fed through the machine and the production can be resumed. The waste queue associated to packaging line 1 producing 500 g of chips is named Q_waste 4. And similarly, Q_waste 5 represents the waste from packaging line 2 producing 200 g of chips.

As mentioned earlier, the chips bags are moved to a controlling process consisting of a metal detector, weight and air-pressure controller, where they are inspected. If defected bags due to different types of errors are detected, they are discarded into a trash bin, figure 15. Q_waste 6 represents waste from packaging line 1 producing 500 g of chips and similarly, Q_waste 7 represents waste from packaging line 2 producing 200 g of chips.

Figure 15: Defected chips bags discarded in trash bins.

It is confirmed that the later products are discarded during production, the higher the associated costs will be; referring to the total amount of waste produced in the packaging section. Stops during the packaging section are difficult to avoid completely due to the highly deviating problems that usually arise and the occurrences of manual operations. Figure 13 indicates that the major part of waste is produced between the manufacturing and packaging section; this amount is even higher than the accumulated amount of waste created in the packaging section. The main focus will therefore be placed on reducing the waste between these two sections, which also contributes to the highest costs, figure 16.

Figure 16: Discarded chips between the manufacturing and packaging section.

4.3 Possible improvement suggestions

Based on the former conducted analyses, different process and work method solutions to the previously discussed problems have been developed. Associated cost analyses and reviews of possible implementations have been included in this phase.

4.3.1 Adjustable forming operation

Applying the pull philosophy on the existing production process is one of the underlying steps of improving and optimizing the process with various Lean concepts. As described earlier, a pull system is based on equipment in progress ordering the necessary amount of taco chips from the previous resource in the production flow. Transforming the process into a pull system makes it achievable to eliminate waste and inventories as much as possible.

The analysed taco chips manufacturing line consists of two main sections, a manufacturing section and a packaging section. Corporation of these two automated sections together results in the final product, Appendix A, figure 1. A huge amount of produced chips is discarded daily between these two sections, due to different types of breakdowns and occurrences of manual work during the packaging section.

The existing production philosophy is based on the push principle where the baking section pushes all produced chips forward to the packaging section. The occurrence of breakdowns in the packaging section results in that nearly all produced chips during the correction of the packaging section is discarded. In order to avoid the occurrence of this situation, the packaging section needs to order the necessary amount of chips from the previous manufacturing section – in other words pull the chips during the production process instead of pushing it forward.

A viable and realistic technical solution to reach a pull production process is to control the speed of the forming operation in the beginning of the manufacturing section. Controlling the operation speed makes it possible to vary the amount of dough formed into chips during the forming operation. Thus the pull principle can be applied between the two main sections of the manufacturing. This will in turn eliminate the huge amount of discarded chips during the occurrence of breakdowns in the packaging section.

With the existing equipment, the thin dough sheet is passed below a forming wheel consisting of differently shaped knives, which cuts out the final shaped chips, figure 17. Triangular, circular and rectangular shapes are the optional forms that can be installed in the forming equipment. The formed chips released from the forming operation are transported further to the baking operation. Currently the speed of the forming operation is independent of any input, which means that the same amount of chips is formed constantly.

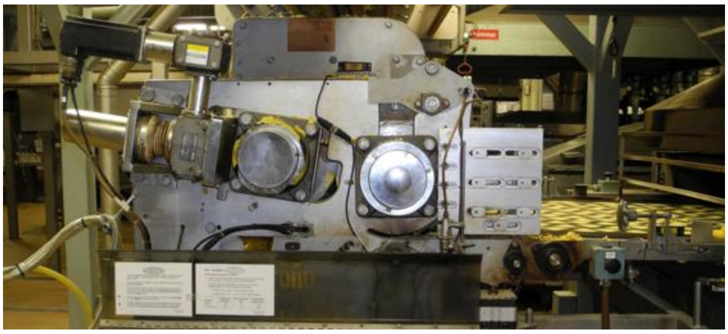

Figure 17: Chips leaving the forming operation during the manufacturing.

Providing the forming operation with a controlling device creates the possibility to adjust the amount of formed chips. The control unit needs to receive orders from the packaging section and set the speed of the forming operation, which in turn releases the necessary amount of formed chips. This suggestion requires a relatively complex signalling system to carry out its function.

The main advantage of implementing this improvement is that the amount of produced chips will be dependent on the demand from the packaging section. In other words, products that cannot be packed are simply not produced!

As a consequence of implementing this improvement suggestion, quality problems including uneven thickness of the chips can arise, which has to be investigated.

A rough cost estimation regarding this improvement suggestion is calculated to approximately 20.000 Euros. This cost only includes material and manufacturing – installation costs will be included during the possible implementation of this improvement suggestion.

4.3.2 Returnable line

As discussed earlier, a huge amount of produced chips is discarded daily between the manufacturing section and the packaging section. This is caused by different types of breakdowns and occurrences of manual operations during the packaging section.

To avoid this problem, a suggestion is to store the amount of chips, which today is discarded, in a buffer. The buffer then returns the stored chips to the production flow when the production rate is lower. The packaging section has to process both the stored chips and the produced chips at the same time. This requires that the accumulated production rate in the packaging section is higher than the production rate in the manufacturing section.

The buffer should be designed as a transportation conveyor, with different running rates, where chips can be stored. This solution is very common in other industries where similar products are produced. Figure 18, presents a proposal conveyor that is used in similar industries.

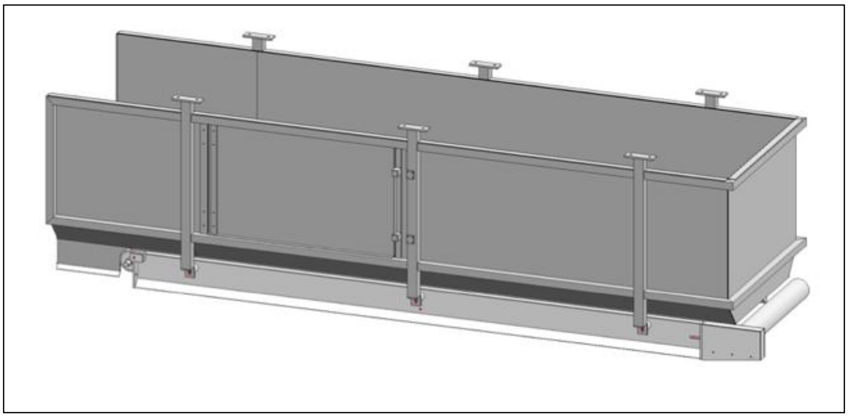

Figure 18: Conveyor that can be used as returnable line.

In order to examine the solution's impact on the existing chip production, an additional buffer was added to the earlier described simulation model. The capacity of this buffer was chosen to 400 kg chips, which is rather reasonable considering the conditions in today's production.

Table 4, presents the output of the production, including an additional returnable line, in a virtual environment during eight hours of simulation. Comparing these results with the current situation, presented earlier in table 3, denotes that roughly 350 kg more chips is produced during the same production period.

Table 4: Output of finished products, during eight hours of production, including a returnable line.

	Packaging line 1 (500 g)	Packaging line 2 (200 g)	Total
Produced pallets	62 pallets	84 pallets	146 pallets
Produced boxes	744 boxes	1680 boxes	2424 boxes
Produced bags	8928 bags	25200 bags	34128 bags
Weight	4464 kg	5040 kg	9504 kg
Distribution	42%	58%	100%

Figure 19 presents the amount of waste produced during the simulation including a returnable line. The main focus was placed on reducing the waste between the manufacturing and packaging sections, i.e. Q_waste 3. The figure indicates that the amount of waste from Q_waste 3 is eliminated totally.

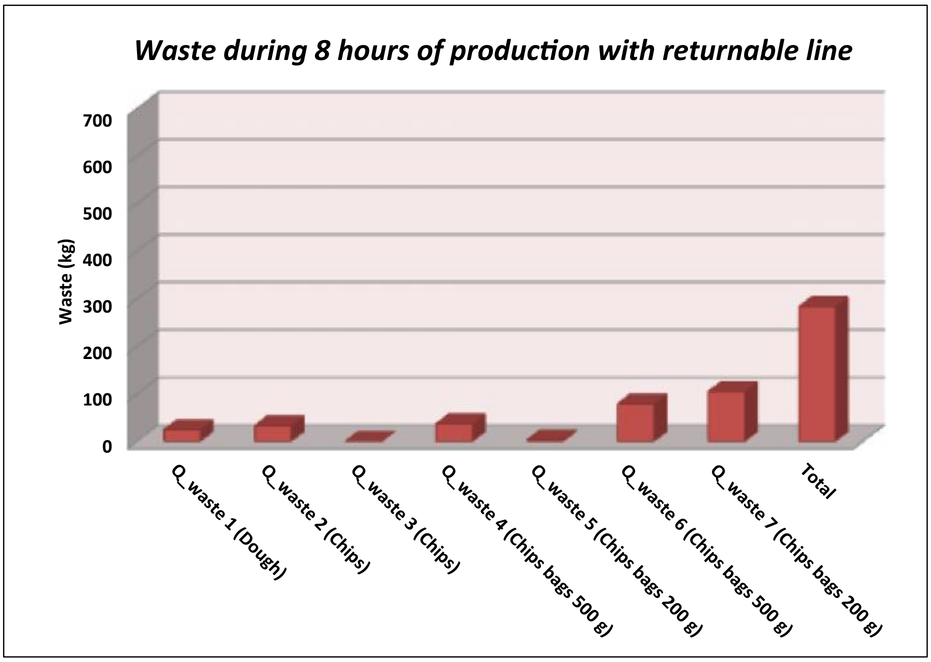

Figure 19: Waste during 8 hours of production including a returnable line.

A detailed comparison of the current waste situation, presented earlier in figure 13, indicates that the amount of waste, in form of chips bags, increases slightly during the packaging section. The additional waste is mainly caused by the production of more defected products, which is a consequence of the increased production output.

It is worth mentioning that this suggested improvement does not correspond to the Lean production philosophies. Through a Lean production perspective, manufacturing products for storage should be avoided. Products that cannot be processed by the current production resource capacity should not be produced at all. Investing in new equipment, in this case a returnable line, with the aim of storing products increases the amount of Work in Progress (WIP). Through a Lean production point of view, the investment itself and the increased amount of WIP are considered as unnecessary activities contributing to further waste.

A cost estimation regarding the described improvement suggestion, which is based on an offer from Santa Maria's system provider, demonstrates that the cost for a returnable line is approximately 48.700 Euros. This cost only concerns the purchasing of the equipment – installation costs will be included during possible implementation of this suggestion.

4.3.3 Adaptable cooling conveyor

The current production process includes a cooling conveyor after the frying equipment in order to cool down the fried chips, figure 20. This conveyor always runs with the same speed during the production independent of the production rate. The consequence of this is that the same amount of chips is constantly transported by the conveyer.

Figure 20: Chips on a cooling conveyor leaving the frying process.

The speed of the cooling conveyor can be related to the amount of chips that can be transported forward. The capacity affects the amount of created waste during the occurrence of breakdowns forward in the packaging section. By running the cooling conveyor with its maximum speed during normal production conditions, all cooled chips can be transported forward to the flavouring platform.

On the contrary, during the occurrence of breakdowns or manual operations, which requires stoppages of one or both packaging lines, the speed of the considered cooling conveyor should be reduced to the minimum. The speed reduction makes it possible to store a huge amount of chips in stock on the same conveyor until the occurred problems forward in the production chain are solved.

The evaluation of this suggestion was prevented by the characteristics of the simulation model. The model of the production is static concerning different properties of entities. The evaluation of this suggestion requires a dynamic model where the parameters of each entity can be updated depending on different circumstances during the execution of the model.

Table 5 demonstrates the transportation time for fried chips on the cooling conveyor. The difference between various speed ranges makes it possible to store additional chips on the same equipment.

Table 5: Transportation time for fried chips on the cooling conveyor.

	Transportation time
Current speed of cooling conveyor	42 sec
Maximum possible speed of cooling conveyor	21 sec
Minimum possible speed of cooling conveyor	160 sec

The approximated cost for implementing this improvement is relatively low in comparison with its benefits. It involves making small adjustments including modifications of the control system to adapt the cooling conveyer to different production rates. The existing process development department at Santa Maria has the knowledge and required tools for initiating the implementation. The cost of various necessary machine parts that have to be purchased is estimated to 2.000 Euros.

4.4 Number of operators

There are many factors that influence the productivity and hence the number of produced products. Work tasks vary depending on the production rate, the machine utilization and the surrounding conditions. The number of operators is related to the number of produced pallets and hence products. A request by Santa Maria was to investigate and simulate the operator utilization to observe the correlation involving the number of operators and the number of produced products. The following analysis is based on the simulated production model, which in turn is created with real statistical data. Each time the simulation model is executed; random data based on the developed statistical distribution are created. The presented figures are all obtained from representative executions, which correspond to the properties of the real life production.

4.4.1 Current state

There are currently three operators working at the chips manufacturing line during an 8 hour shift. Every operator has his/her own responsibility area. Today operator 1 is responsible for the manufacturing section, while operator 2 and 3 are each responsible for packaging lines 1 and 2 respectively. The current state simulation model demonstrates that there is an uneven work distribution between the three operators, figure 21. According to the results, operator 1 is utilized less, while operator 2 and 3 have a rather even utilization distribution. The total number of pallets produced in the simulation model of the current state is 140 pallets – which approximately corresponds to the total number of produced pallets in reality.

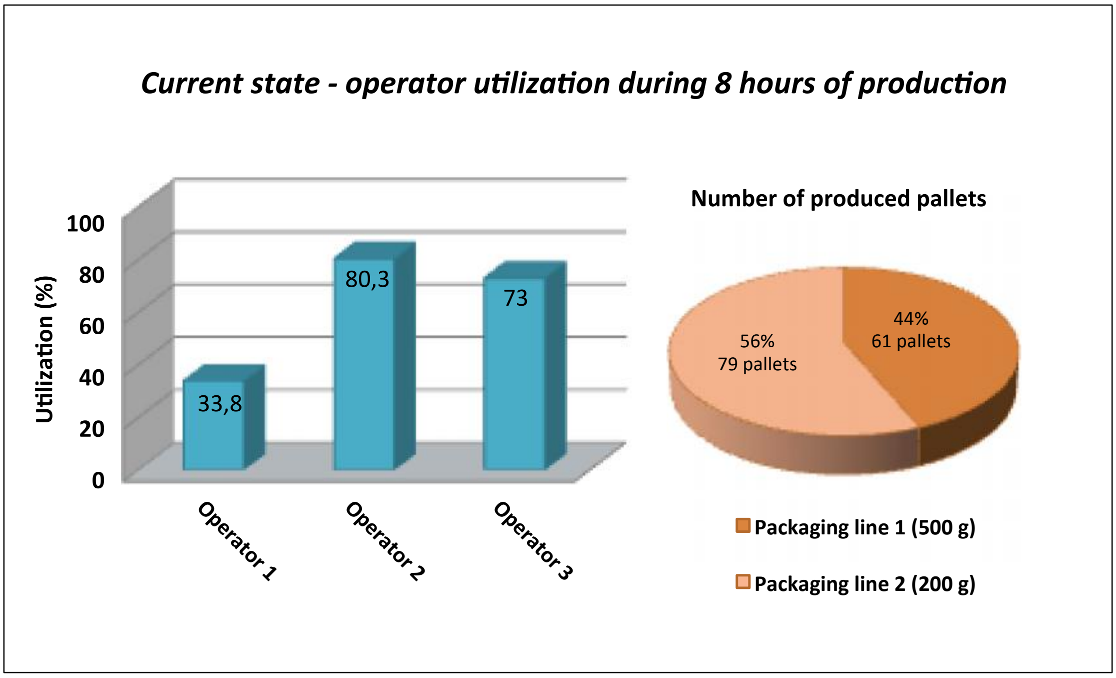

Figure 21: Current state – operator utilization during 8 hours of production.

4.4.2 Increased buffer of empty pallets

Replenishment of pallets occurs often due to a rather small buffer capacity of 15 empty pallets at height. Due to the high frequency, it is rather time consuming compared to the other tasks associated with the chips production. Further, performing this task requires specific knowledge and permission to handle the equipment. Not all operators have this permission, which in turn conflicts with the flexibility of the operators.

The solution of increasing the buffer capacity from 15 to 45, i.e. tripling the capacity, is simulated to observe the operator utilization for predicting the output in reality. Comparing the obtained results in figure 22 to the figures presented earlier, figure 21, the utilization of operator 1 remains unchanged while operator 2 is used less and operator 3 more frequently. Operator 3 seems to be working approximately 15% more than operator 2 due to the increase of breakdowns that is connected to the increased machine utilization. The total number of produced pallets is 142, i.e. 2 pallets more than with the old buffer capacity, which means that the solution is beneficial. In addition, the second operator works less due to the reduction of replenishment of pallets.

Instead of increasing the buffer size, another solution is to reassign the responsibility of replenishing pallets to an exterior truck driver. The reason is that the truck driver is already handling the truck and can probably manage another task.

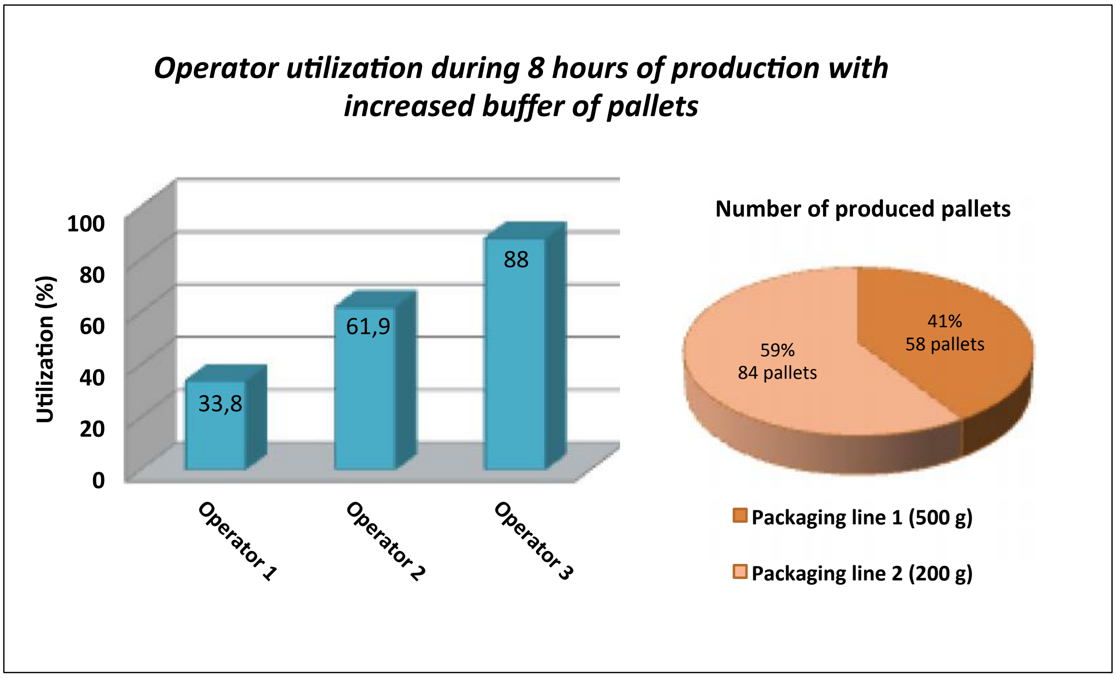

Figure 22: Operator utilization during 8 hours of production with an increased buffer capacity of pallets.

4.4.3 Two operators

An interesting option was to simulate the behaviour of the production if the number of operators is reduced. The main thought is to eliminate the operator that has the lowest utilization, i.e. the operator who is responsible for the manufacturing section.

The solution was simulated and the obtained figures, figure 23, indicate that operator 2 and 3 are used more than 90% of their time – operator 3 is used 96%, which is just about maximum utilization! This solution is rather risky; if more than two parallel problems arise, with only two available operators, longer stops in the production may occur. This will in turn contribute to a stressful situation leading to further problems.

Also, the total number of produced pallets is 132, which are ten produced pallets less than the current situation with 3 operators. It is also worth mentioning that the simulated model does not consider psychosocial factors such as the higher stress level, or human factors such as repetitive work and heavy workload.

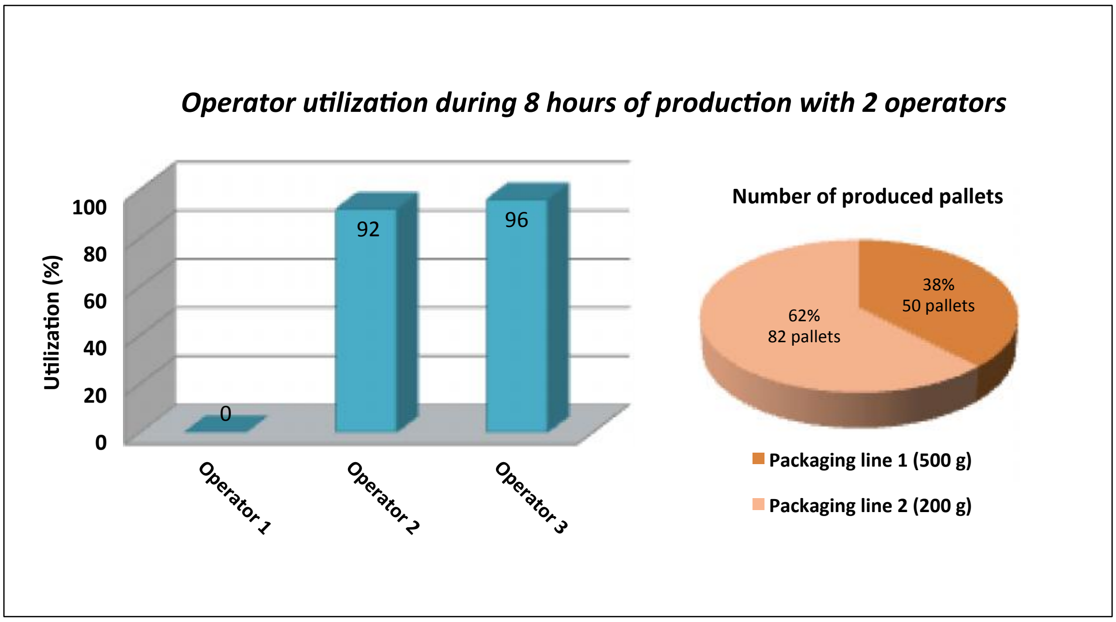

Figure: 23: Operator utilization during 8 hours of production with 2 operators.

5. Results

The main purpose of this project was to analyse the existing chips manufacturing line at Santa Maria through a Lean production perspective. A major part of the project was to locate and review existing waste during manufacturing to obtain a more efficient production. Generally, there is great improvement potential and possibilities to eliminate waste. There are both process-related and organizational problems; focus had to be placed on specific parts of the production and critical operations causing the most waste.

A critical factor was the lack of standardized work instructions, causing unstructured manual operations. In order to organize the work procedures and hence create a more efficient production, standardized work instructions were created. The Predetermined Time System SAM was used to observe and analyse the most repetitive operations and changeovers. The generated standard times for all analysed procedures are presented in table 6. Using these calculated standard times as references makes it possible to distinguish deviations and hence reduce waste in the form of unnecessary or incorrect work steps.

Table 6: Calculated standard times.

Analysed procedures	Calculated standard time
Foil change, packaging line 1	02:03 min
Foil change, packaging line 2	01:28 min
Manual packaging, line 3	01:07 min
Change of product type	07:31 min

At a very early stage, it became rather obvious that the major part of waste is created between the manufacturing and the packaging section. The main causes are occurrences of breakdowns and manual operations during the packaging section, which contributes to the waste. Regarding waste elimination, various improvement suggestions have been developed and analysed, and some of the solutions have also been evaluated virtually. Table 7 introduces the different solutions including their estimated investment costs, benefits and drawbacks.

Table 7: Developed improvement suggestion with their associated properties.

Improvement suggestion	Estimated cost	Benefits	Drawbacks
Adjustable forming operation	20.000 €	Pull based solution	Costly to implement
Returnable line	48.500 €	More suitable for longer stops	Against Lean
Adoptable cooling conveyer	2.000 €	Easy to implement. Provides immediate results. Relatively low cost.	Less suitable for longer stops

6. Discussions and Conclusions

The project in general has been very motivating and enlightening; great opportunities were given to apply theoretical knowledge on real-life problems. The initiation of the project was a bit complex; the goal and scopes were changed several times during the project. Also, carrying out a project in the food industry was rather new and challenging.

Due to the time constraints, a few limitations were selected during the project. These included mostly aspects concerning human factors and organizational structure problems. It is worth mentioning that these aspects are critical and affect the output of the production as much as process-related problems. Based on the results of the conducted interviews with concerned employees, it is rather noticeable that there is a motivational decrease. The underlying factors might in general be a lacking organization and insufficient competency. It is recommended to emphasize these issues in order to reduce further waste in the production, caused by non process-related problems. Also, psychosocial factors may affect the work motivation, such as the level of noise, illumination, working space and surrounding temperature. Regarding the analysed production at Santa Maria, there is great improvement potential in all the mentioned areas.

Lean production is a comprising philosophy that originates from the car manufacturing industry, and must therefore be adapted to different types of production. It is worth mentioning that only the relevant parts of Lean have been concerned throughout the project. Adapting Lean production principles on an existing production line has been demanding. Applying pull principles on an existing push based production requires radical changes, which in turn is contradictory with the Lean philosophy of small incremental changes.

The developed standardized work instructions are mainly based on recorded work operations, which might have been insufficiently representative. The selected analytical tool SAM is mostly suitable for reviewing manual assembly operations and is mostly used to obtain total standard times. The adaption to the current production at Santa Maria has been partly demanding. The two mentioned lacks might have affected the results. Further, through a Lean production perspective, using standard times to pressure workers is counterproductive – it results in a stressful environment and prevents individual development. Therefore, it has been mentioned throughout the analysis that the standard times should merely be used as guidelines for planning and further improvement.

The developed simulation model of the production is mainly based on data provided by Santa Maria. A vital weakness originates from deficiencies in the documentation that affect the output of the simulation model. The provided data compilation was not sufficiently detailed, which resulted in additional empirical measures and estimations. Further, the simulation does not consider the current circumstances or other important aspects, such as human factors. A few of the developed improvement suggestions could be evaluated by using the simulation model. The remaining solutions were difficult to simulate due to the characteristics of the model.

The purpose of the thesis partly included developing improvement suggestions; these are based on realistic solutions that can be implemented in the current production. The suggested process improvements are in an initial concept phase and can be further developed with detailed technical properties. This in turn has affected the level of detail of the estimated investment costs.

In general, the simulation phase was experienced as the most difficult and time consuming part of the project, both regarding the data gathering process and the programming. The lack of knowledge and experience of Discrete Event Simulation was the main reason for the faced complexity. However, a representative model was developed, which was beneficial in the waste detection phase and partly in the validation process.

To conclude, the current circumstances and characteristics of the chips production line at Santa Maria prevents total elimination of the existing waste. However, Lean production philosophies of continuously improving the production and eliminating waste is an ideal goal worth striving for.

The developed standardized work instructions can be used to structure and organize the production. Standardizing tasks is a fundamental part of Lean production; continuously improving the standards hence contributes to the reduction of waste. The obtained standard times should be used as references for further improvement and should not be used to pressure the workers.

The evaluated improvement suggestions should also contribute to waste reduction if implemented. The key point is to find the most profitable balance in the production and consider that the higher the speed of the processes, the more waste is created and discarded.

7. Recommendations and future improvements

Since the project has been time constrained, only the chips production line has been addressed. The remaining lines of the production consist of manual operations that have great improvement potential regarding various aspects. For future work, it is recommended to also analyse the remaining production at Santa Maria to get a more holistic perspective.

Another area that this project does not review to a great extent is the motivational and human factors problems, psychosocial factors, and environmental friendly production philosophies. These different areas may also be addressed for future improvements. Further, ergonomic aspects should be considered during future improvement work. Although ergonomic improvements have been conducted earlier at Santa Maria, there are still repetitive tasks and demanding operations, including heavy workload, which can be improved further. Therefore, it is recommended to develop the conducted SAM analysis with the additional ergonomic evaluation method ErgoSAM.

Generally, eliminating waste is not only cost beneficial, it also contributes to a more sustainable production. Through an environmental friendly viewpoint, the current recycling routines should be reviewed and improved for reduced environmental impact.

Finally, it is very common that the arising problems do not depend on the internal processes at the company, but on the suppliers. Good communication and collaboration with the suppliers creates the possibility to avoid future problems. For future work, it is suggested to investigate whether the problems originate from the suppliers, and in that case require feedback and support.

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Appendix A – Production Process Flow, HTA

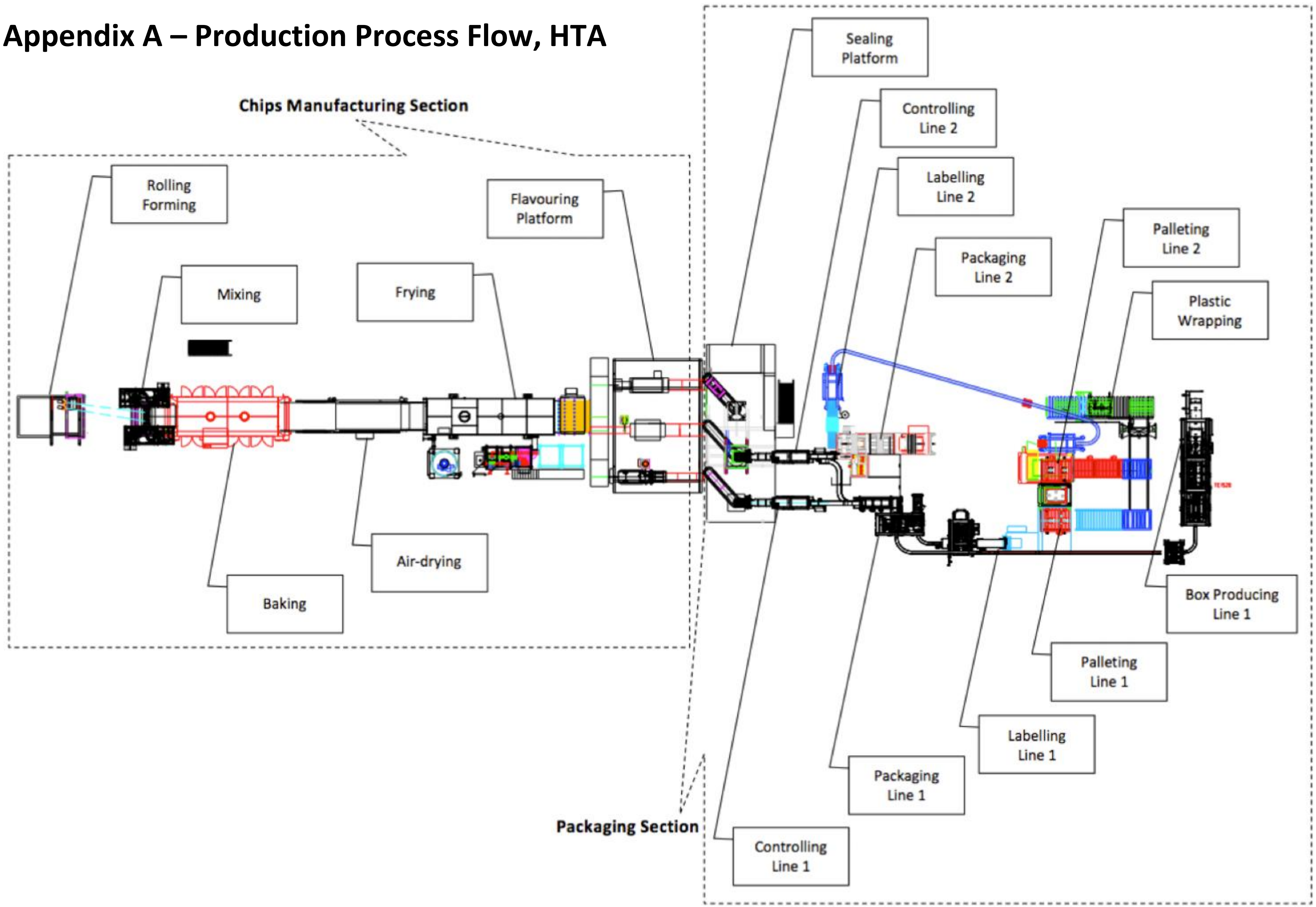

Figure 1: Overview of production flow.

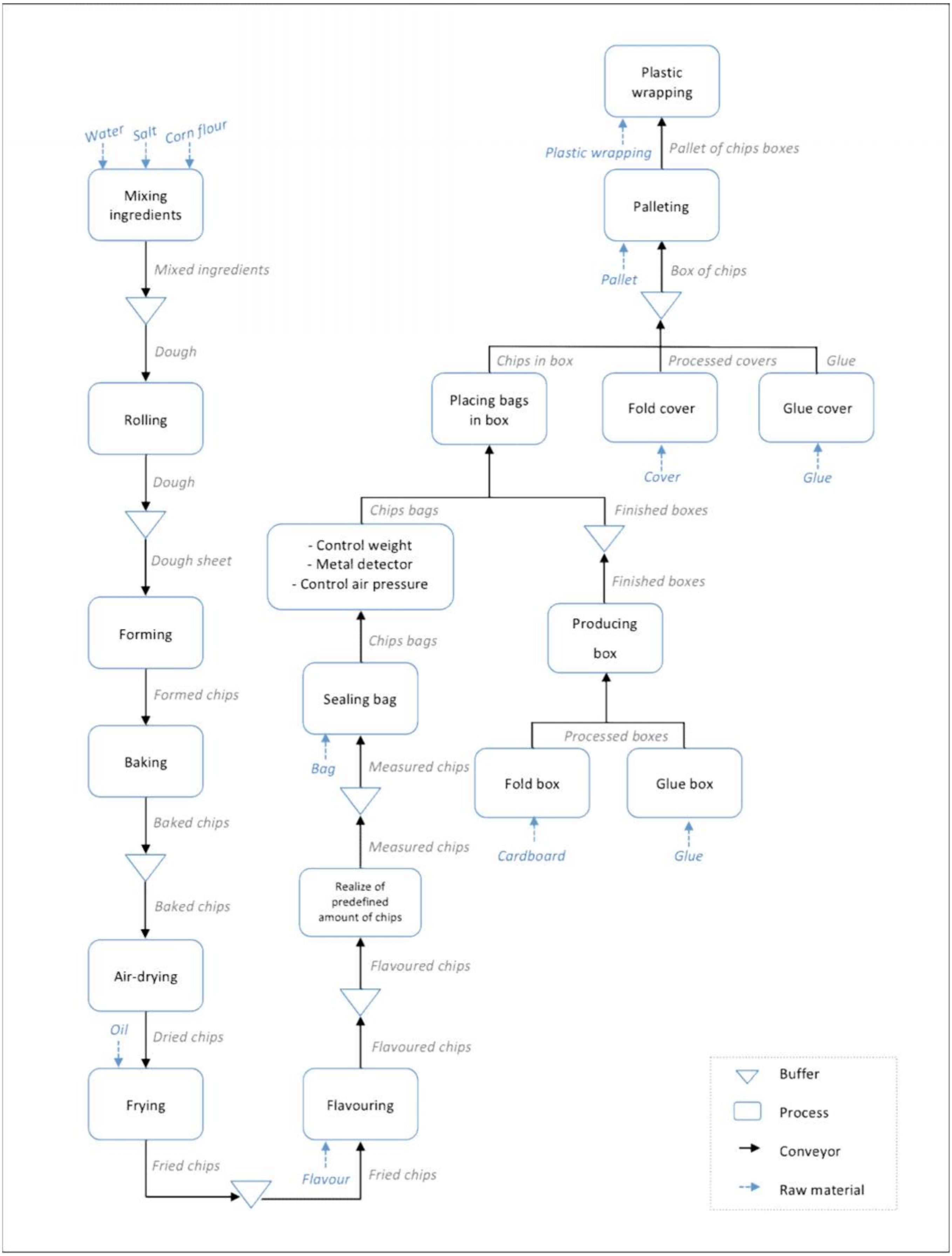

Figure 2: Production process flow of packaging line 1.

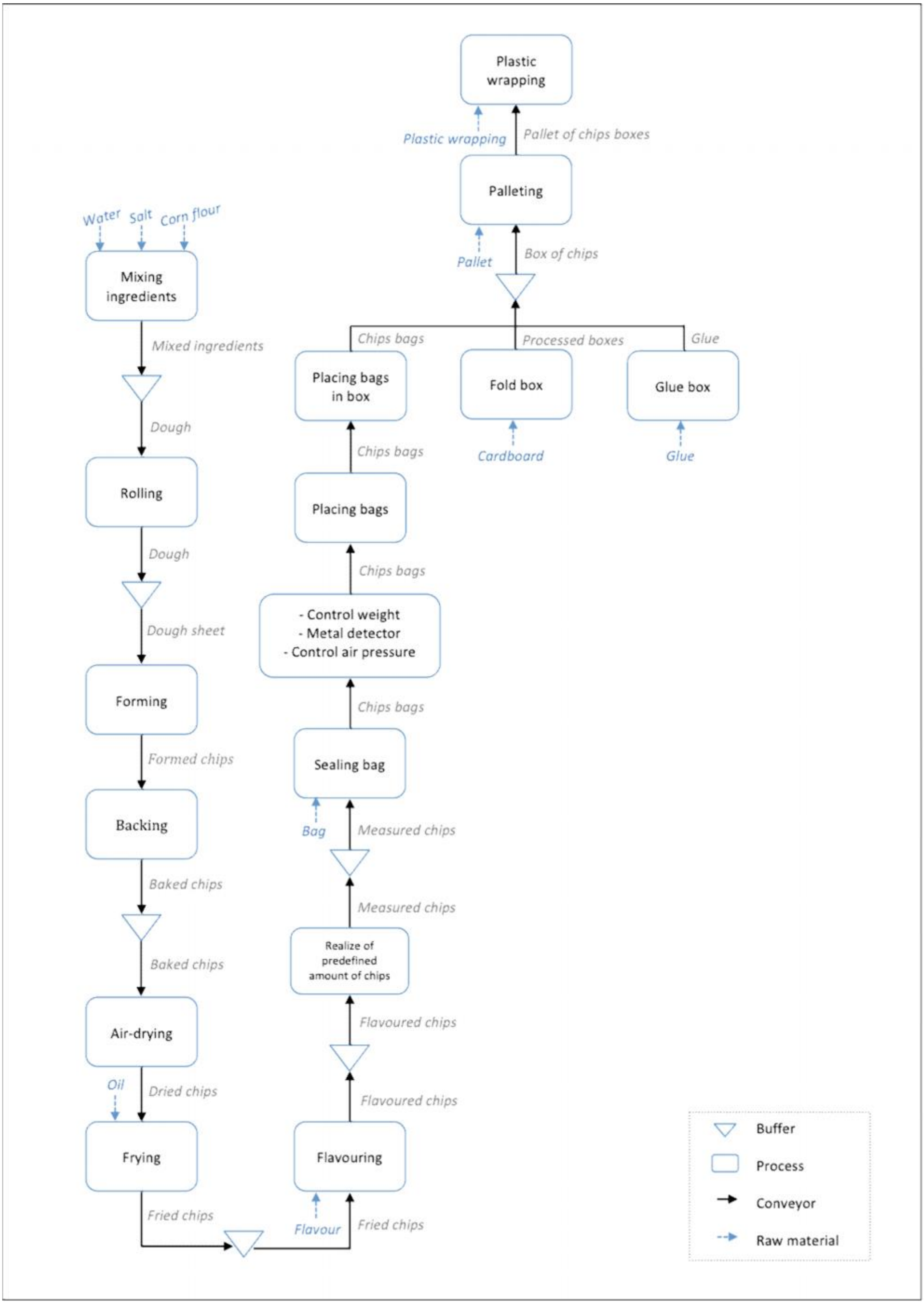

Figure 3: Production process flow of packaging line 2.

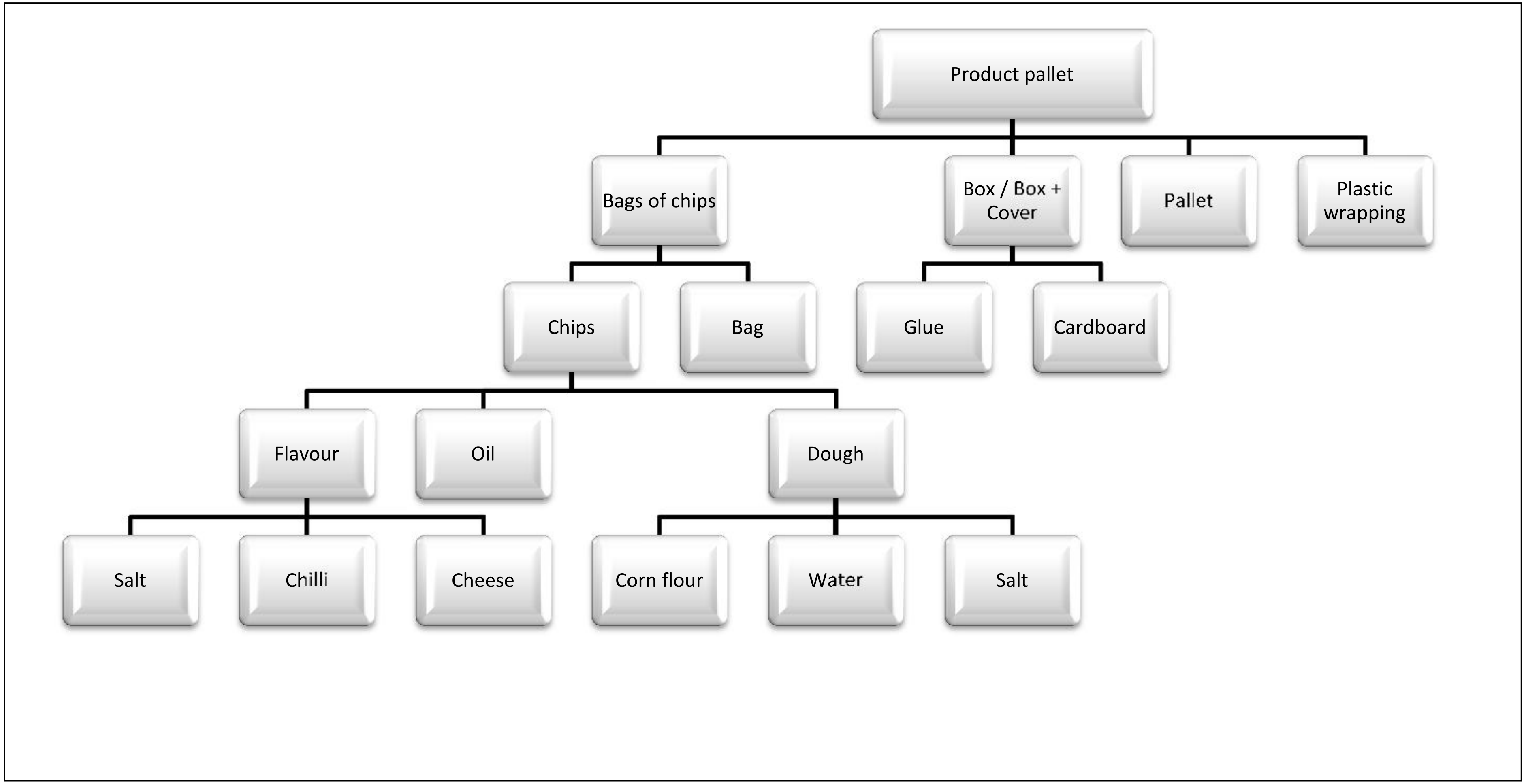

Figure 4: Material Hierarchical Task Analysis.

Appendix B – Value Stream Mapping Symbols

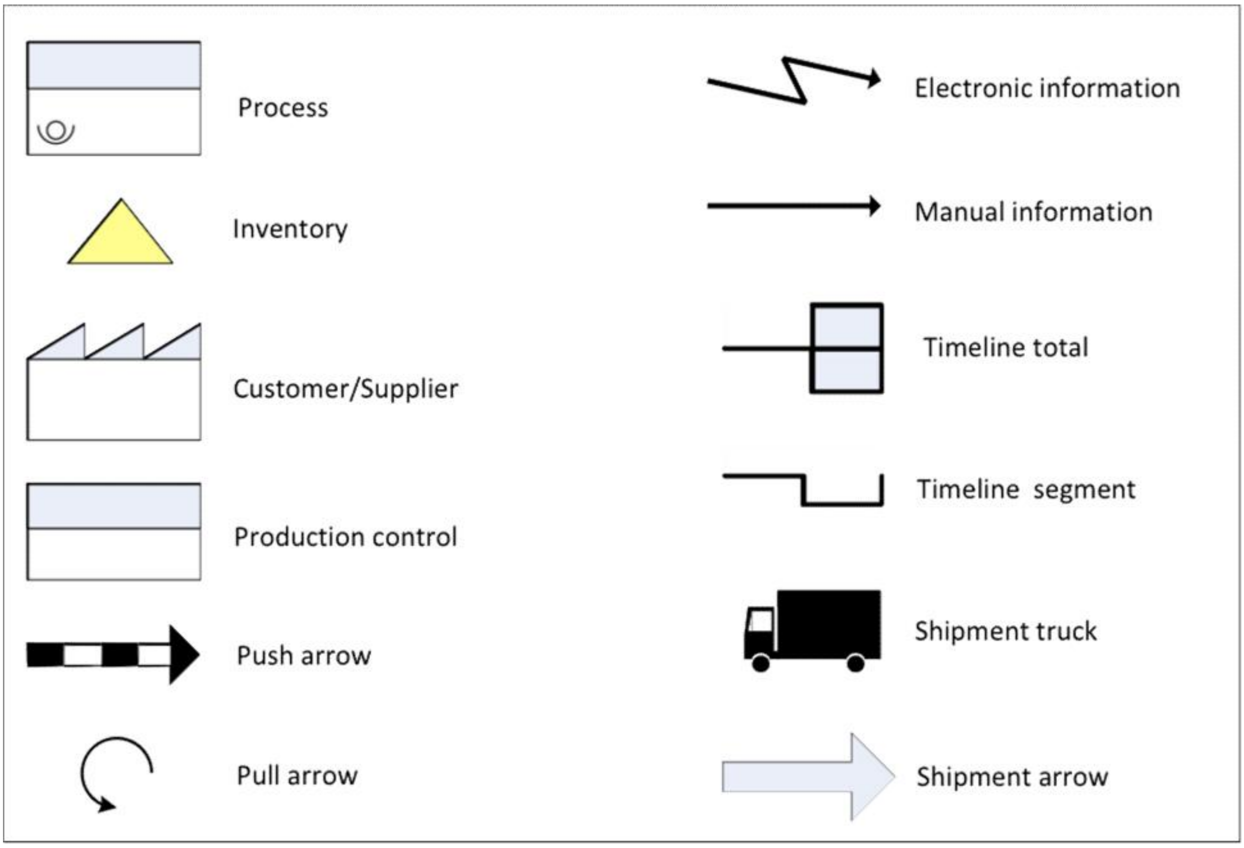

Figure 1: Symbols used to create a Value Stream Map.

Appendix C – Interviews

Interview with Annika Christensson, Production planner and purchaser at Santa Maria
21 Mars 2012, 10:00

1. Who is Santa Maria's final customer and where are they located?
The final customer is Santa Maria's main storage in Kungsbacka, Sweden. The warehouse stores all products manufactured by Santa Maria including spices, Tex Mex products, barbeque products etc. The warehouse in turn delivers the different products to various grocery stores; the delivery unit in this case is chips boxes.

2. How and where does the customer make an order? How frequent are the orders?
The Tex Mex products are produced based on previously conducted forecasts. If a specific order arises, the warehouse immediately contacts the planning and purchasing department at Santa Maria. An Enterprise Resource Planning system (ERP) called MoveX is used to control inventory records and various other parameters of interest. The production planning is based on the different orders placed in MoveX. Deviating orders must be placed at least six weeks before delivery.

3. How often are products transported to the customer?
Trucks from an external company deliver products from Santa Maria to the main warehouse 5-6 times a day. The truck has the capacity of loading 66 pallets and is fully loaded during transportation.

4. Who are Santa Maria's material suppliers for:
Flour: There are three suppliers; Maselis (Belgium) and two other suppliers from France and Italy.
Salt: Salt is purchased from the supplier Hanson och Möhring.
Spices: All spices are delivered from Santa Maria's spice factory in Mölndal.
Oil: The oil is supplied by AarhusKarlshamn (AAK).
Cardboard-boxes: The cardboard-boxes are supplied by Stora Enso.
Glue: Glue is supplied by H.B. Fuller from Portugal.
Foil: Foil is ordered from Italy by an external purchaser.

5. How often are orders placed for raw material?
The production planner keeps track of the raw material consumption and places orders depending on the usage. Also, MoveX senses the availability of material and suggests purchasing when a minimum amount is reached. The delivery of flour takes about 6 weeks, therefore proper planning is important. The cardboard-boxes are delivered much faster; Stora Enso stores finished Santa Maria boxes and can deliver these in two days. Spices are also delivered rapidly, either the same day or the next day.

6. Are the orders sent/placed electronically or manually?
Purchasing orders are created and sent electronically to the current supplier by email.

7. Who is responsible for the deliveries and how often do they occur?
The supplier is responsible for the deliveries to Santa Maria's raw material storage. It sometimes occurs that raw material is incorrectly delivered to Santa Maria's spice factory across the street. In general, deliveries from Sweden are faster than those from abroad, but it mainly depends on where the supplier is located and the type of material.

8. How often are production plans made; weekly or monthly?
Production plans are made weekly but the production planner creates preliminary plans on a monthly basis.

9. How is the operator/team leader informed about the production plan? How often does it occur?
A copy of the production plan is sent to all team leaders, technical managers, production manager and the plant manager. Also, the daily production plan is published on the production board to demonstrate what and how much that needs to be produced. Changeovers are included in the production plan for the operators to follow. Planning is made on a weekly basis but the operators receive a daily production plan.

Interview with Mats Gardtman, Production manager at Santa Maria
25 April 2012, 14:00

1. What is your current work position?
Mats is the current production manager of the whole taco manufacturing and has had the same position for the previous 2.5 years.

2. How many are employed at Santa Maria?
There are in total 20 employees (including operators and team leaders) working the day and night shift in the factory. The night shift has 8 working operators including team leader. Santa Maria has in total approximately 70 employees, including operators and officials.

3. Regarding work instructions, has Santa Maria tried to accomplish standardized work instructions?
The development of Standard Operation Processes (SOP) is currently in progress. The project has been initiated in parts of the factory; currently the developed work descriptions are being verified and in April 2013 they will be confirmed. The aim is that all production lines should have completed SOP's until the end of the year. There is also a parallel occurring project, namely an Operation Production System (OPS) project that originates from the Toyota Production System (TPS). Further, the SOP project proceeds with the chips production line. The project initiates with developing SOP's for the manufacturing section and proceeds in the production flow. A few SOP's will be created earlier than others due to different priorities. The SOP's are currently created by three trained operators; the aim is to train at least three operators per shift in SOP-creating.

The responsibility of the organizational structure is today placed on process engineers, project engineers and technicians. Mats adds that it is more beneficial to instead transmit this responsibility to a new work position called production engineer. The operators develop the best work methods subjectively during the creation of SOP's. According to Mats, a problem with standardization in the process industry is that the SOP's obtain a wide tolerance window. Some parameters depend on perception and experience, which makes it difficult to standardize.

Root cause analysis and fish bone diagrams are often used to resolve problems, unfortunately a limited number of operators have the knowledge of using these tools

4. It is noticed that the production mostly stops during lunch breaks, how long are the breaks and how often do they occur?
Every day there is a unique priority, based on customer orders, that indicates which line that can be stopped during lunch breaks. If the chips line has lower priority, it can be stopped and the operators can have breaks. Otherwise, it runs constantly during three shifts. Partly, low presence can cause stops during lunch breaks; the total amount of operators are then not sufficient to run all lines during lunch breaks.

5. What happens if someone is absent or late?

There is an overcapacity on the lines, which is not fully utilized. There are 20 workers per shift; 17 are sufficient for running all 4 lines including stops during lunch break. The worst-case scenario is that one line receives a lower priority and is stopped during the day, or that two lines are stopped during breaks. It is very difficult to use consultants or staffing employees due to the perception and experience dependent production. There is a concept of establishing a trained student pool, which can be reached easily in need.

6. What is the approach if errors occur?

The production manager receives reports on all stops that occur during the production. The reports are various kinds of manually created Key Performance Indicators (KPI), in other words total times that the machines are stopped.

Regarding mechanical stops, the technology department is responsible for addressing various types of occurring problems. The production manager expects the processes to function properly in order to plan the production. The focus is placed on solving problems with the three most problematic machines, with the most occurring breakdowns. The Overall Equipment Efficiency (OEE) for the whole factory was in average 68% during last year. Santa Maria’s goal is to reach an OEE of 73%.

7. Which machines have the most recurring problems? Are bug reports delivered? What is your opinion of the waste on the chips line and what causes it?

There are different opinions regarding the most problematic machine; according to Mats, it is the packaging machine for line 2. Detailed root cause analyses indicate that the sealing machine is the main cause. Technical issues are partly responsible for the way the chips bags leave the machine. Further, the surrounding environment is not optimal – a few accidents with cheese-chips leave grease coatings on the equipment, which in turn affects the way the bags move in the machine.

Currently the management is discussing the solution of placing back bags into the production. Mats rejects this proposal due to the quality problems associated with it. The bags involved in failures have probably been piled and stuck in the machine, which means that they are also probably smashed. The risk of selling bad quality products is receiving dissatisfied customers. Placing back a product that has been involved in a failure is hence not recommended. Instead, the root causes should be grasped to hopefully eliminate future problems.

Further, there is a hired technician working on improving the packaging machine on line 2 continuously. The supplier of the machine has gone out of business. Also, the machine has been modified to suit Santa Maria’s production; purchasing basic equipment and implementing modifications makes it difficult to complain about a non-functioning machine.

8. Regarding the high temperature and the high noise level in the production, has any improvement work been attempted?
A project of decreasing the noise level was conducted in 2004-2005. The noise level was then higher than it is today! Today's noise level is in the range of 80-85 dB, which is approved with hearing protection by the Work Environment Act.
Regarding the high temperature, solutions with cooling air has been considered. Unfortunately, the properties of the factory do not allow this solution due to building restrictions. The solution has therefore been transferring the surrounding air by using fans, which makes it cooler.

9. Have comments been received regarding the availability of protective equipment?
Earmuffs are personal and each operator is responsible for their individual earmuffs. Hearing protection is available in the production department and is assigned to operators in need.

10. If a work accident occurs – what efforts have been made to prevent future risks and accidents?
Work accidents occur seldom, on the other hand there are occurring incidents. Incidents are defined as occurrences that might cause accidents. All incidents are filed as reports and are reviewed with work safety and risk analyses. The incident analyses are conducted by an assigned work environment group consisting of employees from the technology, protection and process departments at Santa Maria. The reports seldom include employees being injured – the last approved work injury occurred 1994! Nevertheless, the incidents indicate a risky environment – everything from slippery floor to various equipment can cause accidents.

11. Have efforts been made to assess the work environment in the production? If so, what were the results and has the situation been improved since?
Six months ago, the work motivation was assessed with the aid of a work environment analysis. The analysis was divided into seven different groups, Santa Maria has selected four of these; two of them are leadership and well being. The responsible work group consists of a safety representative, various managers and three operators. Proposed solutions are developed by the groups' opinions.

12. Have efforts been made to assess the work ergonomics in the production?
Ergonomic analysis has previously been conducted by an external consultant on the final packaging of chips, during running of flavoured chips where the following operations were in focus:
Cleaning out chips bags during machine stops
Changing foil-rolls with the aid of mechanical lifting
Replenishing flavour, 13 kg flavour bag standing on stair ladder
Cleaning during the replenishment of flavour
Handling of waste containers
Manual replenishment of cardboard-boxes
Manual handling of finished chips boxes when the packaging section has been out of order (weight per box is 6 kg)

13. What are your opinions regarding solving the existing production related problems focusing on waste elimination?

The production manager agrees that a pull system should be strived for, and that the need or availability further down in the production chain should determine the production pace. The chips line is a straight process that requires storage that handles the items in the manufacturing section. The idea has been there for some time and the interest for solving the problems are now increasing.

Improvements for the last two years have resulted in that the total number of workers has decreased from 27 (1^{st} shift), 27 (2^{nd} shift), 27 (night shift) to 20 (1^{st} + 2^{nd} shift) and additional 8 (night shift). Note that the production is still the same. The improvements have not cost anything, which means that a lot of savings have been made.

Interviews with operators and the group leader at Santa Maria
15 February 2012, 09:30

1. How long have you worked at Santa Maria?
The team leader has worked at Santa Maria for 11.5 years and the carrier length regarding the operators varies from 6 months up to several years.

2. What are your work tasks?
They mainly work in the production and have the overall responsibility for the chips production line. The team leader has individual work instructions that have to be followed.

3. Are there specific workstations assigned to each operator or does rotation occur?
There are 4 workers at the chips production line in total, including 3 operators and one team leader. The operators are usually responsible for the maintenance of the chips line. One works at the manufacturing section and the remaining two at the packaging section.

4. Are there any existing work instructions?
There are some SOP's but the management is currently working on establishing new SOP's. Problems may arise with the documentation due to the characteristics of the work operations.

5. How many operators work / shift?
As mentioned earlier, there are three operators and one team leader each shift. The amount of breakdowns would decrease if the current problems with the packaging section were solved. The production would it that case only require two operators; one operator responsible of the manufacturing section and the other one of the packaging section.

6. How often do breaks occur?
The break is divided between the three operators who replace each other. If there is a full staff the production is not stopped.

7. What happens if someone is absent or late?
The best possible balance between the production lines is tried to be achieved. Sometimes operators from the other taco lines need to assist the chips line; this is not very appreciated due to the stressful situation at the chips line and not all operators have the knowledge. One solution is that two operators work continuously on the chips line, and a third operator rotates and helps.

8. What is the common approach if errors occur?
The total amount of stops are documented in standard sheets and further sent to the management. The stops are documented in minutes; a weakness is that the stop length is rounded up to the largest possible minute. Also, it occurs that operators forget and for this reason do not document exact values.

9. Which machines have the most recurring problems?
The packaging machine on line 2 is the most problematic one; the company tried to make savings and did not purchase the best machine on the market.

10. What is your opinion regarding the waste on the chips line?
When products are discarded in the later parts of the production, it becomes more costly. When the chips bags are jammed in the packaging machine, finished products have to be discarded due to the defective equipment.

11. What is causing the waste?
The major reason is the recurring stops and problems with the packaging machine on line 2. A huge amount of chips is therefore discarded after the manufacturing section.

12. On a scale from 1-10, how tired are you after a whole work shift?
It varies depending on the total number of stoppages during the shift. Generally, the exhaustion is on a scale of 5-6 and mostly it depends on the heat.

13. Can you explain briefly how a changeover proceeds?
The management is working on developing SOP's for the changeovers, which are rather inefficient today. One reason is lack of competence among the operators that perform the changeovers. Changeovers often occur between shifts.

14. What do you think about the temperature at the work place?
The temperature is high and can reach up to 50 degrees during summer. Fans are available but are not that useful – it is better than nothing.

15. What do you think about the noise level at the work place?
A project of decreasing the noise level was conducted recently. The noise level has lately increased to 98dB.

16. Do you think it is crowded in the factory?
Yes, it is very crowded, especially on Fridays when cleaning occurs – it complicates the whole process.

17. Is protective equipment (goggles, hair net, gloves) available for you?
Hearing protection is available at the production department and is assigned to operators in need.

18. Are you satisfied with the contact with the team leader?
The operators turn to the team leader. The team leader in turn usually solves the problems by himself or contacts the management.

19. Are you satisfied with your colleagues?
"People who work here do not want to work here – they do it because they have to!". The organization has its flaws and the communication between the management and the shop floor is weak. The collaboration between operators and their team leaders functions well.

20. Do you feel that you have the possibility to grow at the work place?
Newly recruited operators feel that the work is instructive and challenging while more experienced operators feel the opposite. Operators should be educated and trained to manage all work tasks – this will in turn increase their flexibility and improve their individual development.

21. Has anyone been involved in an accident at the work place?
Work accidents occur seldom, however developing additional safety instructions is never wrong. The following work accidents have occurred:
A fire was caused by the oil in the frying machine; it was extinguished and no one was injured.
One operator broke his arm during waste disposal (tipping of the trash bin).
An official received a heavy lump of dough in the head with serious injuries.

22. If there were opportunities to change something in the production, what would it be in the first place?
The problems with the packaging machine should be dealt with in the first place to reduce waste and the amount of stops. The company should also focus on competence growing actions for the workers. The team leader believes that applying Lean production philosophies, which originate from the automotive industry, is difficult at Santa Maria's production.

Appendix D – Value Stream Mapping – VSM

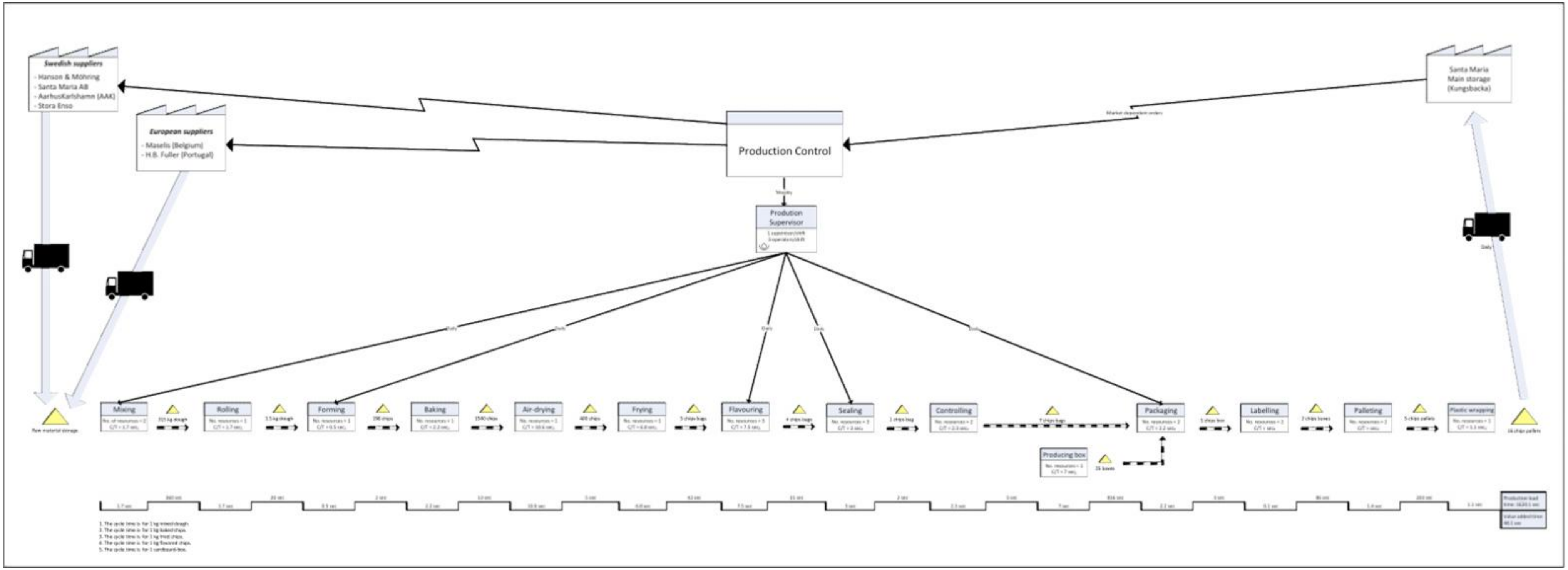

Figure 1: Current Value Stream Map. A larger image is available in the following pages.

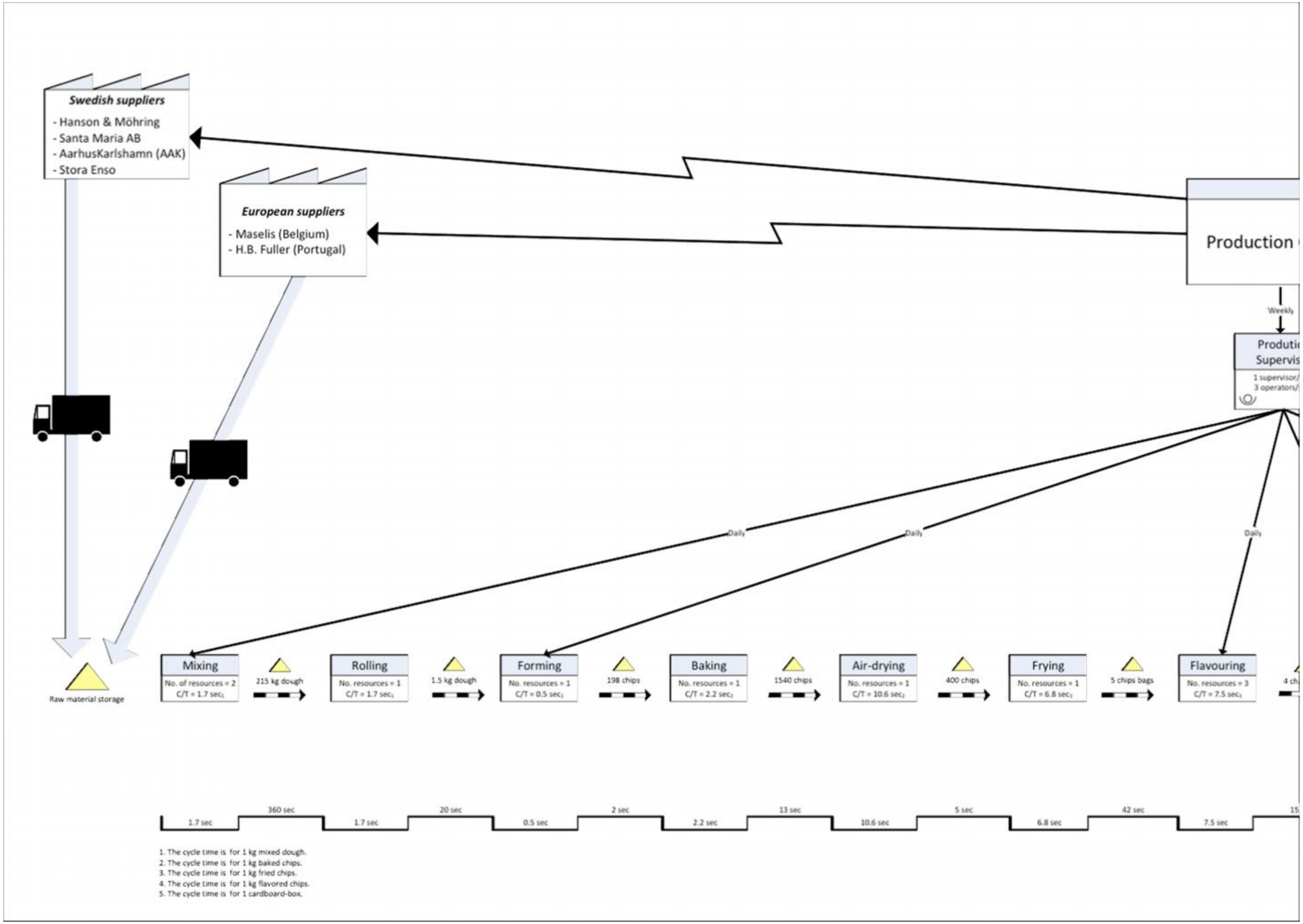

Figure 2: Current Value Stream Map. (First part)

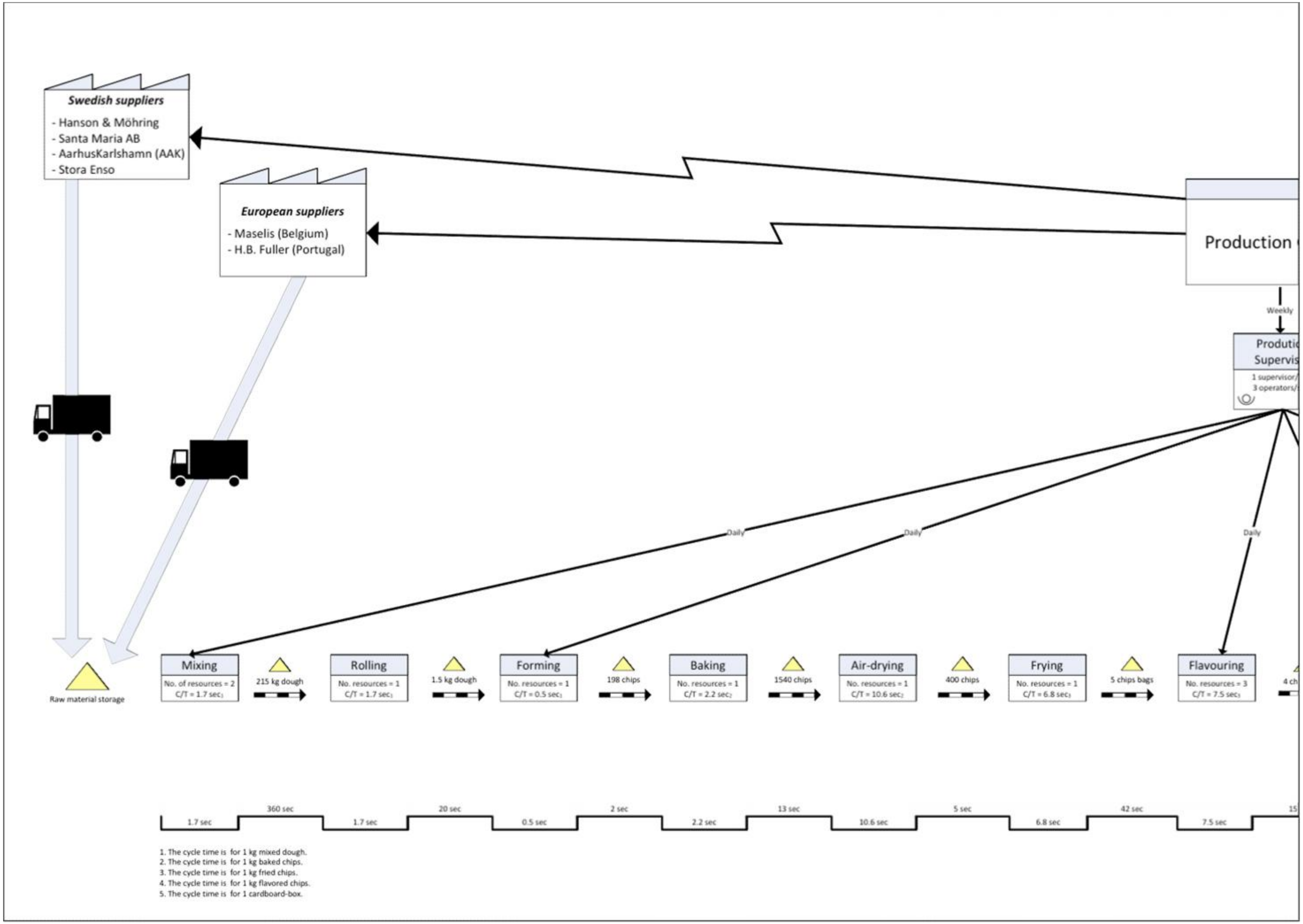

Figure 3: Current Value Stream Map. (Second part)

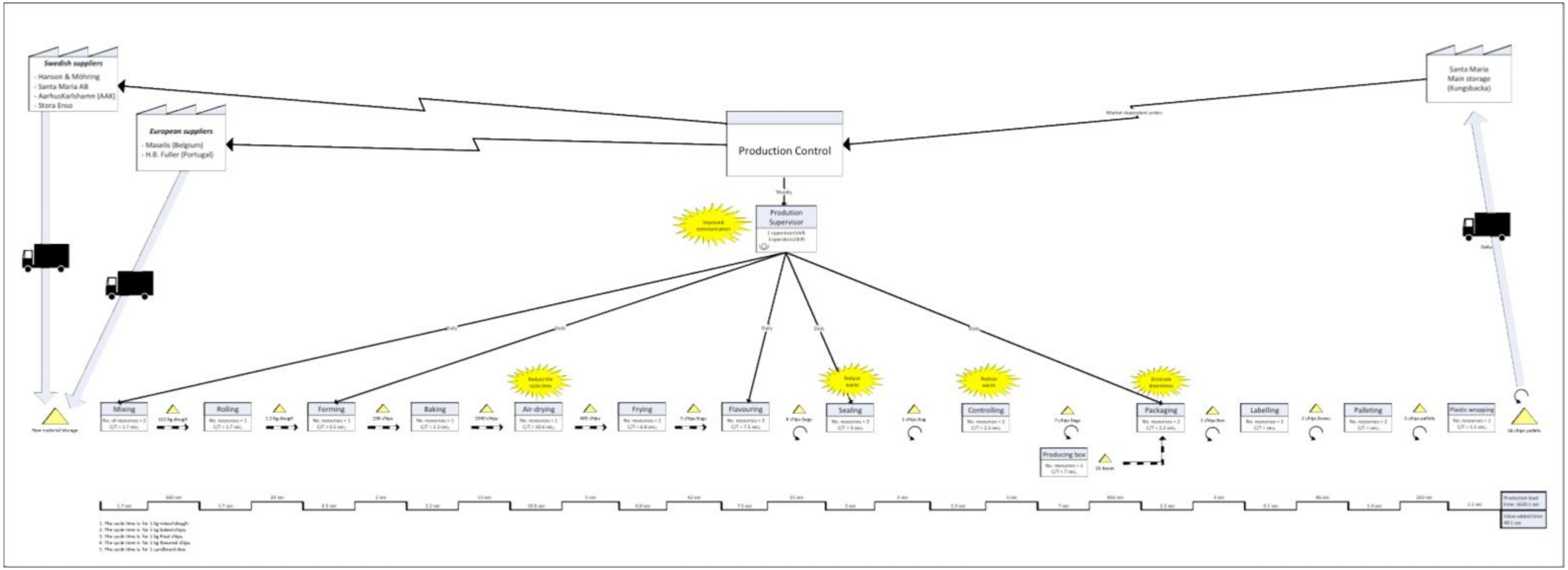

Figure 4: Future Value Stream Map. A larger image is available in the following pages.

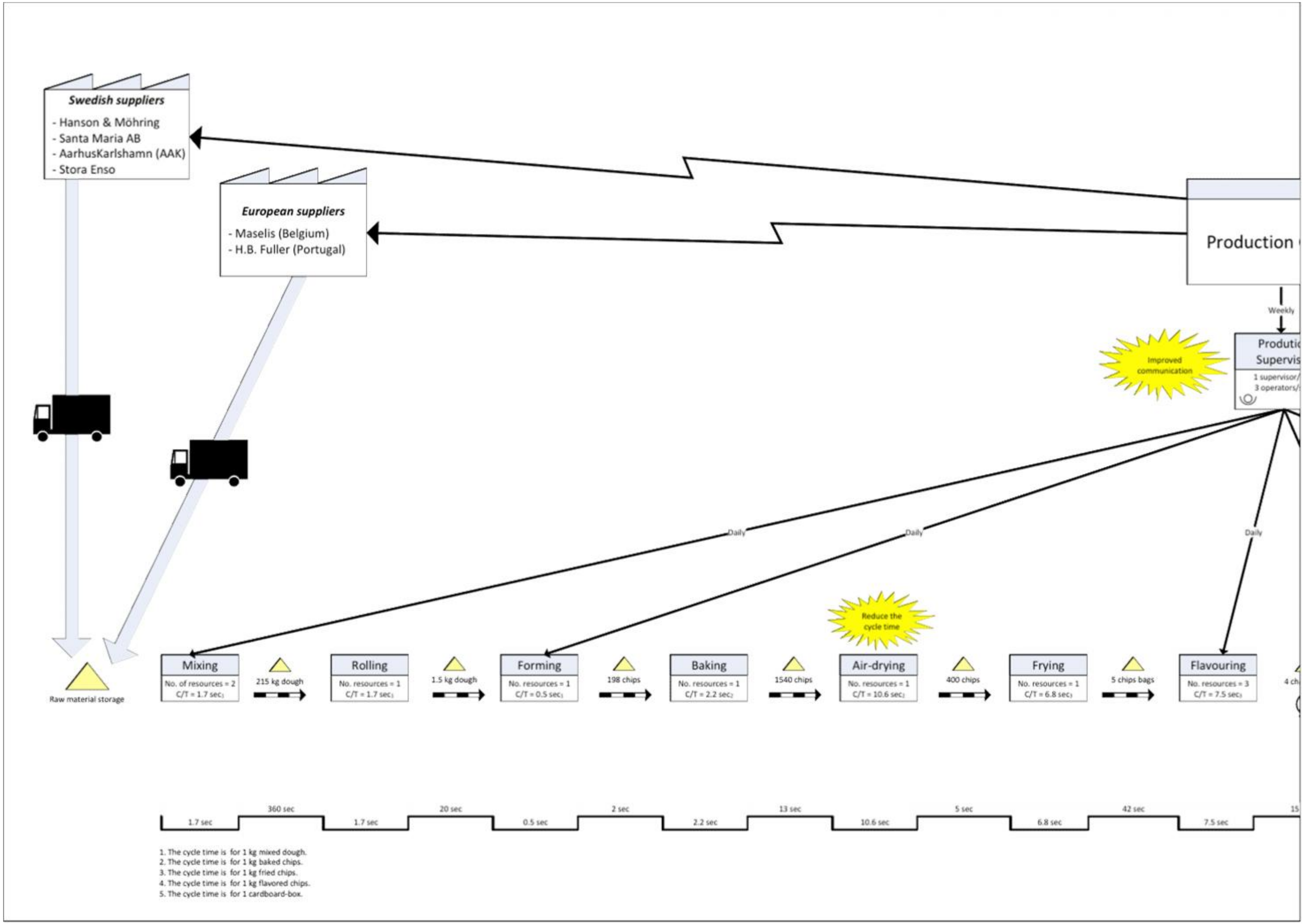

Figure 5: Future Value Stream Map. (First part)

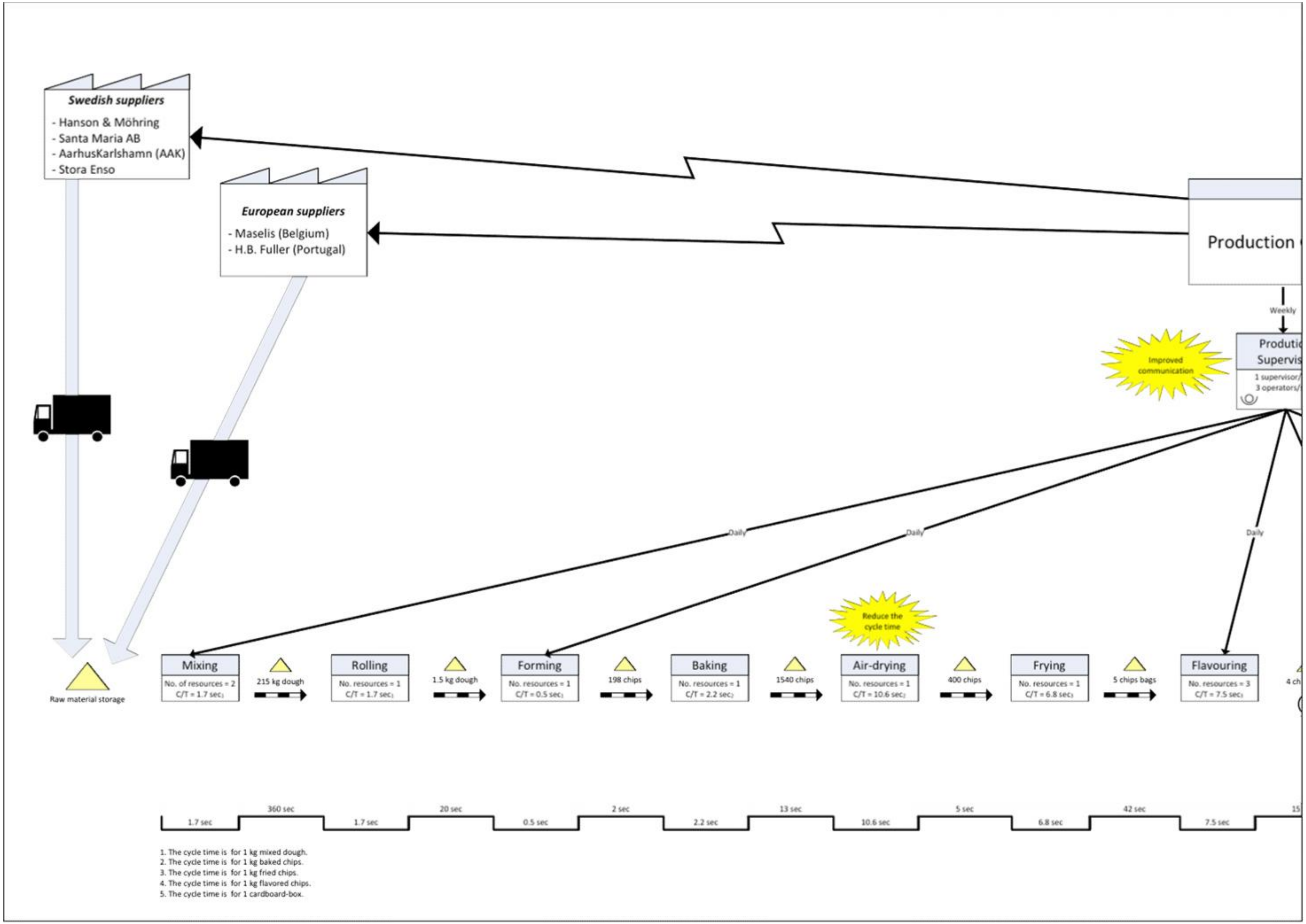

Figure 6: Future Value Stream Map. (Second part)

Appendix E – Sequence-Based Activity and Method Analysis – SAM

	SAM Analysis Form																				1 hour = 20 000 factor						
The analysis belongs to Santa Maria - TEX MEX										Date: 2012-04-14																	
Operation: Foil change, line C1										Issued by Chalmers University of Technology											Page 1 of 2						
	GET					**PUT**							**USE**					**RETURN** PUT							**Summing up** Factors		
	Step	GS			Add. for Handful	Weight >5 kg	Step	PD			Add. for Precision	Apply Force	No.of strokes, grips etc..	No.of places	Time of stroke,prip etc		Apply Force	Weight > 5 kg	Step	PD			Add. for Precision	Apply Force	Bend+Arise			
Method description	S	80	45	10	-H	AW	S	80	45	10	-P	AF					AF	AW	S	80	45	10	-P	AF	B			
	3	5	4	2	6	2	3	5	4	2	3	3	f	n	t	=	3	2	3	5	4	2	3	3	12	F	f	Total
1. Prepare the foil by removing the plastic wrapping		3		2																					1			
		15		4																					12			31
2. Tilt down and rotate the foil roll		1				1		1																	1			
		5				2		5																	12			24
3. Switch the machine to manual mode	3	1											1	1		CA(3)												
	9	5														3												17
4. Get the feeder and lift it up		1						1																				
		5						5																				10
5. Take the knife, cut the foil and discard it	1	1						3	1		3								1	1								
	3	5						15	4		9								3	5								44
6. Release and lift the shaft upwards		1		1		1		1																	1			
		5		2		2		5																	12			26
7. Place the shaft on the pallet and remove the empty foil roll		1				1	3	2																	1			
		5				2	9	10																	12			38
8. Get the shaft and insert it into a new prepared foil		1				1		2			1	3													1			
		5				2		10			3	9													12			41
9. Get the air gun, use it on the shaft and return it	6	1					6	1		1	1									1					1			
	18	5					18	5		2	3									5					12			68
10. Get shaft with roll, insert and lock it in the machine	2	1				1	7	1		1	1														1			
	6	5				2	21	5		2	3														12			56
11. Take the tape off the new foil	2	1							1	2	1																	
	6	5							4	4	3																	22
12. Insert foil in the machine slot		1						1	3		1														1			
		5						5	12		3														12			37
13. Enable feeder and place the foil on the cutting plate		2		1				1			1																	
		10		2				5			3																	20

	SAM Analysis Form	1 hour = 20 000 factor
The analysis belongs to Santa Maria - TEX MEX	Date: 2012-04-14	
Operation: Foil change line C1	Issued by Chalmers University of Technology	Page 2 of 2

Method description	GET					PUT							USE					RETURN PUT								Summing up Factors		
	Step	GS			Add. for Handful	Weight >5 kg	Step	PD			Add. for Precision	Apply Force	No.of strokes, grips etc..	No.of places	Time of stroke,prip etc		Apply Force	Weight > 5 kg	Step	PD			Add. for Precision	Apply Force	Bend+Arise			
	S	80	45	10	-H	AW	S	80	45	10	-P	AF					AF	AW	S	80	45	10	-P	AF	B			
	3	5	4	2	6	2	3	5	4	2	3	3	f	n	t	=	3	2	3	5	4	2	3	3	12	F	f	Total
14. Get the knife and use it		1						2			1									1								
		5						10			3									5								23
15. Get tape and tape the separate foils together	6	1					6	1				1	2	1		FA((5)												
	18	1					18	5				3				10												55
16. Switch the machine to automatic mode, go to the screen and start the machine		1		1			9	1			1		2	1		PA(2)												
		5		2			27	5			3					4												46
17. Wait until the foil intersection (tape) is visible															90	T												
																90												90
18. Stop the bag-cutter and feed the foil		1	1										1	2		PA(2)												
		5	4													4												13
19. Start the cutter and remove the discarded bags		1						1					1	1		PA(2)									1			
		5						5								2									12			24
Calculation																		Total net time (factors/sec)										685/123

Figure 1: Conducted SAM analysis concerning the foil change operation on packaging line 1.

External activities	
Internal activities	

	SAM Analysis Form	1 hour = 20 000 factor
The analysis belongs to Santa Maria - TEX MEX	Date: 2012-04-14	
Operation: Foil change, line C2	Issued by Chalmers University of Technology	Page 1 of 2

Method description	**GET**					**PUT**							**USE**					**RETURN PUT**							**Summing up Factors**			
	Step	GS			Add. for Handful	Weight >5 kg	Step	PD			Add. for Precision	Apply Force	No.of strokes, grips etc..	No.of places	Time of stroke,prip etc		Apply Force	Weight > 5 kg	Step	PD			Add. for Precision	Apply Force	Bend+Arise			
	S	80	45	10	-H	AW	S	80	45	10	-P	AF					AF	AW	S	80	45	10	-P	AF	B			
	3	5	4	2	6	2	3	5	4	2	3	3	f	n	t	=	3	2	3	5	4	2	3	3	12	F	f	Total
1. Prepare the foil by removing the plastic wrapping		3		2																					1			
		15		4																					12			31
2. Tilt down and rotate the foil roll		1				1		1																	1			
		5				2		5																	12			24
3. Insert the foil roll onto the free shaft		1				1	2	1			1														1			
		5				2	6	5			3														12			33
4. Get the air gun, use it on shaft and return it		1						1			1									1			1		1			
		5						5			3									5			3		12			33
5. Take the knife, cut the foil and return it		1						2			2									1								
		5						10			6									5								26
6. Release and tilt the occupied shaft upwards		1		1		1		1																				
		5		2		2		5																				14
7. Insert the prepared shaft with the foil into the machine		1					1	1				1																
		5					3	5				3																16
8. Tilt down the empty shaft		1						1																				
		5						5																				10
9. Take the tape off the new foil		1							1	2	1																	
		5							4	4	3																	16
10. Insert foil in the machine slot and place the foil on the cutting plate		1						1			1														1			
		5						5			3														12			25
11. Get tape and tape the separate foils together		1						1				1	2	1		FA((5)												
		5						5				3				10												23
12. Fold the residual tape on the other side of the foil		2								3	2																	
		10								6	6																	22
13. Switch the machine to automatic mode, go to the screen and start the machine	6	1						1					1	5		PA(2)												
	18	5						5								10												38

SAM Analysis Form		1 hour = 20 000 factor
The analysis belongs to Santa Maria - TEX MEX	Date: 2012-04-14	
Operation: Foil change, line C2	Issued by Chalmers University of Technology	Page 2 of 2

Method description	GET					PUT							USE					RETURN PUT								Summing up Factors		
	Step S	GS 80	GS 45	GS 10	Add. for Handful -H	Weight >5 kg AW	Step S	PD 80	PD 45	PD 10	Add. for Precision -P	Apply Force AF	No.of strokes, grips etc.. f	No.of places n	Time of stroke,prip etc t	=	Apply Force AF	Weight > 5 kg AW	Step S	PD 80	PD 45	PD 10	Add. for Precision -P	Apply Force AF	Bend+Arise B	F	f	Total
	3	5	4	2	6	2	3	5	4	2	3	3	f	n	t	=	3	2	3	5	4	2	3	3	12	F	f	Total
14. Wait until the foil intersection (tape) is visible															73	T												
																73												73
15. Press and hold down the feeding button to feed the foil		1											1	1	84	PA(2), T												
		5														86												91
16. Start the cutter and remove the discarded bags		1											1	3		PA(2)									1			
		5														6									12			23
Calculation																		Total net time (factors/sec)										490/88

Figure 2: Conducted SAM analysis concerning the foil change operation on packaging line 2.

External activities	
Internal activities	

	SAM Analysis Form	1 hour = 20 000 factor
The analysis belongs to Santa Maria - TEX MEX	Date: 2012-04-28	
Operation: Manualt packaging, line C3	Issued by Chalmers University of Technology	Page 1 of 1

Method description	GET					PUT							USE					RETURN PUT								Summing up Factors		
	Step S	GS 80	GS 45	GS 10	Add. for Handful -H	Weight >5 kg AW	Step S	PD 80	PD 45	PD 10	Add. for Precision -P	Apply Force AF	No.of strokes, grips etc.. f	No.of places n	Time of stroke,prip etc t	=	Apply Force AF	Weight > 5 kg AW	Step S	PD 80	PD 45	PD 10	Add. for Precision -P	Apply Force AF	Bend+Arise B	F	f	Total
	3	5	4	2	6	2	3	5	4	2	3	3	f	n	t	=	3	2	3	5	4	2	3	3	12	F	f	Total
1. Take a cardboard box		1						1																				
		5						5																				10
2. Fold the cardboard box		1						4				1																
		5						20				3																28
3. Rotate the cardboard box and place it on the table		1					5		1																			
		5					15		4																			24
4. Take a plastic bag and insert it in the cardboard box		1						1			1		5	1		FA(7)												
		5						5			3					35												48
5. Get the prepared box and place it in the fixture		1					5	1			1																	
		5					15	5			3																	28
6. Start the equipment and wait until enough amount of chips is released		1											1	1	45	PA(2), T												
		5														47												52
7. Get the filled chips box and prepare it for sealing		2	4					2	4																			
		10	16					10	16																			52
8. Take the sealing strip and seal the plastic bag		1						1		4	1	1																
		5						5		8	3	3																24
9. Fold the filled chips box, shake and rotate it		1	1					1	1				3	1		FA(5)				1								
		5	4					5	4							15				5								38
10. Get the tape gun and seal the filled chips box		1						1			1		1	1		FA(7)	1			1								
		5						5			3					7	3			5								28
11. Get the sealed chips box and place it on the pallet		1					9	1																				
		5					27	8																				40
Calculation																		Total net time (factors/sec)										372/67

Figure 3: Conducted SAM analysis concerning the manual packaging operation on packaging line 3.

SAM Analysis Form

1 hour = 20 000 factor

The analysis belongs to Santa Maria - TEX MEX | Date: 2012-04-19

Operation: Change of product type, line C2 | Issued by Chalmers University of Technology | Page 1 of 3

Method description	GET					PUT							USE					RETURN PUT								Summing up Factors		
	Step	GS			Add. for Handful	Weight >5 kg	Step	PD			Add. for Precision	Apply Force	No.of strokes, grips etc..	No.of places	Time of stroke,prip etc		Apply Force	Weight > 5 kg	Step	PD			Add. for Precision	Apply Force	Bend+Arise			
	S	80	45	10	-H	AW	S	80	45	10	-P	AF					AF	AW	S	80	45	10	-P	AF	B			
	3	5	4	2	6	2	3	5	4	2	3	3	f	n	t	=	3	2	3	5	4	2	3	3	12	F	f	Total
1. Turn off the packaging line by pressing the stop button	6	1											1	1		PA(2)												
	18	5														2												25
2. Go up to the flavouring platform	46	1						1				1																
	138	5						5				3																151
3. Put on the protection clothes		1						3			2																	
		5						15			6																	26
4. Rotate the flavour container	9	1						1				1																
	27	5						5				3																40
5. Remove the sensor from the container		1						1																				
		5						5																				10
6. Get shovel, use it to empty the containera and return the shovel	1	1					1	1					7	1		FA(7)				1								
	3	5					3	5								49												65
7. Change the setting of the falvouring machine	2	1											1	3		PA(2)												
	6	5														6												17
8. Turn off the flavouring machine			1										1	1		CA(3)				1								
			4													3				5								12
9. Disassemble the existing feeder housing	4	1											1	1		CA(3)	4		3	1								
	12	5														3	12		9	5								46
10. Disassemble the existing spiral feeder	3	1											1	1		FA(7)	1											
	9	5														7	3											24
11. Clean out the remaining flavour with the spiral feeder and return it											5		5	1		FA(7)			3	1								
											15					35			9	5								64
12. Get the container and mount it on the existing one	10	1					10	1			1																	
	30	5					30	5			3																	73
13. Lock all four fastners		4							4		4	4																
		20							16		12	12																60

	SAM Analysis Form	1 hour = 20 000 factor
The analysis belongs to Santa Maria - TEX MEX	Date: 2012-04-19	
Operation: Change of product type, line C2	Issued by Chalmers University of Technology	Page 2 of 3

Method description	GET					PUT							USE					RETURN PUT								Summing up Factors		
	Step	GS			Add. for Handful	Weight >5 kg	Step	PD			Add. for Precision	Apply Force	No.of strokes, grips etc..	No.of places	Time of stroke,prip etc		Apply Force	Weight > 5 kg	Step	PD			Add. for Precision	Apply Force	Bend+Arise			
	S	80	45	10	-H	AW	S	80	45	10	-P	AF					AF	AW	S	80	45	10	-P	AF	B			
	3	5	4	2	6	2	3	5	4	2	3	3	f	n	t	=	3	2	3	5	4	2	3	3	12	F	f	Total
14. Palce the sensor in its position		1						1																				
		5						5																				10
15. Get the the new sprial feeder and the feeder housing	10	1					10	1																				
	30	5					30	5																				70
16. Mount the new spiral feeder on the flavouring machine		1						1			1	1																
		5						5			3	3																16
17. Mount the new feeder housing on the flavouring machine		1						1			1	1	2	1		CA(3)							1	1				
		5						5			3	3				6							3	3				28
18. Start the feeding equipment	2	1											1	1		CA(3)												
	6	5														3												14
19. Check and stop the feeding equipment	2						2						1	1	3	CA(3)												
	6						6									3												15
20. Get ladder and place it next to the flavouring machine	4	1					3	1																				
	12	5																										17
21. Get flavour bags and put it on the ladder	9	1				1	9	1																	1			
	27	5				2	27	5																	12			78
22. Get the knife and cut the bag		1						1					4	1		FA(5)												
		5						5								20												30
23. Fold up the bag and climb up on the ladder			1			1	2																					
			4			2	6																					12
24. Tilt the bag, empty its content in the container and discard the empty bag								1					3	1		FA(5)				1								
								5								15				5								25
25. Start the flavoruing machine and rotate the containor to its original position	2	1											1	1		CA(3)			2	1				1				
	6	5														3			6	5				3				28
26. Get 3 more flavour bags and put them on the ladder	27	3				3	27	3																	3			
	81	15				6	81	15																	36			234

	SAM Analysis Form	1 hour = 20 000 factor
The analysis belongs to Santa Maria - TEX MEX	Date: 2012-04-19	
Operation: Change of product type, line C2	Issued by Chalmers University of Technology	Page 3 of 3

Method description	GET					PUT							USE					RETURN PUT								Summing up Factors		
	Step	GS			Add. for Handful	Weight >5 kg	Step	PD			Add. for Precision	Apply Force	No.of strokes, grips etc..	No.of places	Time of stroke,prip etc		Apply Force	Weight > 5 kg	Step	PD			Add. for Precision	Apply Force	Bend+Arise			
	S	80	45	10	-H	AW	S	80	45	10	-P	AF					AF	AW	S	80	45	10	-P	AF	B			
	3	5	4	2	6	2	3	5	4	2	3	3	f	n	t	=	3	2	3	5	4	2	3	3	12	F	f	Total
27. Get the knife and cut the bags		3						3					4	3		FA(5)												
		15						15								60												90
28. Fold up the bags and climb up on the ladder			3			3	6																					
			12			6	18																					36
29. Tilt the bag, empty its content in the container and discard the empty bag								3					3	3		FA(5)				3								
								15								45				15								75
30. Take off the protection clothes	9	2						2			1																	
	27	10						10			3																	50
31. Go down and start the packaging line	46	1						1				1	1	1		PA(2)												
	138	5						5				3				2												153
32. Discard 90 bags from the packaging line	3	90						90																				
	9	450						450																				909
Calculation																		Total net time (factors/sec)										2503/451

Figure 4: Conducted SAM analysis concerning the change of product type operation on packaging line 2.

Appendix F – Standard Operation Procedure – SOP

Santa Maria	Standard Operating Procedure SOP	Department	Production	Date	03/05/2012
		Section	Chips line	Work sheet	S.O.P Master
Plant	Taco Plant	Process	Foil change, line C1	Page	Page 1 of 1
Takt Time	N/A	Product	Taco chips		
Cycle time (Min)	2.05 min	Risk Assessment	N/A		

PRODUCE AGAINST BUFFER · SAFETY · ERGONOMICS · LARGE IMPACT ON QUALITY · QUALITY CONTROL

Layout work sequence

Step	Work step	Time - Element (Sec) Manual	Autom.	Step	"Key points" Safety, Quality, Cost, Technology
1	Prepare the foil by removing the plastic wrapping	6			
2	Tilt down and rotate the foil roll	4			
3	Switch the machine to manual mode	3			
4	Get the feeder and lift it up	2			
5	Take the knife, cut the foil and discard it	8			
6	Release and lift the shaft upwards	5			
7	Place the shaft on the pallet and remove the empty foil roll	7			
8	Get the shaft and insert it into a new prepared foil	7			
9	Get the air gun, use it on the shaft and return it	12			
10	Get shaft with roll, insert and lock it in the machine	10			
11	Take the tape off the new foil	4			
12	Insert foil in the machine slot	7			
13	Enable feeder and place the foil on the cutting plate	4			
14	Get the knife and use it	4			
15	Get tape and tape the separate foils together	10			
16	Switch the machine to automatic mode, go to the screen and start the machine	8			
17	Wait until the foil intersection (tape) is visible	16			
18	Stop the bag-cutter and feed the foil	2			
19	Start the cutter and remove the discarded bags	4			
20					
21					
22					
23					
24					
	Total:	123			

	DATE	OPR	TL	PM	MAINT	QA	SAFETY
Work shift A							
Work shift B							
Work shift C							
Issue 1							
Created by	Chalmers University of Technology						
Approved by							

Lock	Protective goggles	Protective shoes	Protective gloves	Hearing protection	Protective screen	Protective clothes	Protective helmet	Dust protection

Figure 1: Conducted SOP concerning the foil change operation on packaging line 1.

Santa Maria	Standard Operating Procedure SOP	Department	Production	Date	03/05/2012
		Section	Chips line	Work sheet	S.O.P Master
Plant	Taco Plant	Process	Foil change, line C2	Page	Page 1 of 1
Takt Time	N/A	Product	Taco chips		
Cycle time (Min)	1.52 min	Risk Assessment	N/A		

PRODUCE AGAINST BUFFER ● | SAFETY | ERGONOMICS | LARGE IMPACT ON QUALITY | QUALITY CONTROL

Step	Work step	Time - Element (Sec) Manual	Autom.	Step	"Key points" Safety, Quality, Cost, Technology
1	Prepare the foil by removing the plastic wrapping	6			
2	Tilt down and rotate the foil roll	4			
3	Insert the foil roll onto the free shaft	6			
4	Get the air gun, use it on shaft and return it	6			
5	Take the knife, cut the foil and return it	6			
6	Release and tilt the occupied shaft upwards	3			
7	Insert the prepared shaft with the foil into the machine	3			
8	Tilt down the empty shaft	2			
9	Take the tape off the new foil	3			
10	Insert foil in the machine slot and place the foil on the cutting plate	4			
11	Get tape and tape the separate foils together	4			
12	Fold the residual tape on the other side of the foil	4			
13	Switch the machine to automatic mode, go to the screen and start the machine	7			
14	Wait until the foil intersection (tape) is visible	13			
15	Press and hold down the feeding button to feed the foil	16			
16	Start the cutter and remove the discarded bags	4			
17					
18					
19					
20					
21					
22					
23					
24					
	Total:	91			

Layout work sequence

	DATE	OPR	TL	PM	MAINT	QA	SAFETY
Work shift A							
Work shift B							
Work shift C							
Issue 1							
Created by	Chalmers University of Technology						
Approved by							

Lock	Protective goggles	Protective shoes	Protective gloves	Hearing protection	Protective screen	Protective clothes	Protective helmet	Dust protection

Figure 2: Conducted SOP concerning the foil change operation on packaging line 2.

Santa Maria	Standard Operating Procedure SOP	Department	N/A	Date	03/05/2012
		Section	Chips line	Work sheet	S.O.P Master
Plant	Taco Plant	Process	Manualt packaging, line C3	Page	Page 1 of 1
Takt Time	N/A	Product	Taco chips		
Cycle time (Min)	1.01 min	Risk Assessment	N/A		

PRODUCE AGAINST BUFFER | SAFETY | ERGONOMICS | LARGE IMPACT ON QUALITY | QUALITY CONTROL

Step	Work step	Time - Element (Sec) Manual	Autom.	Step	"Key points" Safety, Quality, Cost, Technology
1	Take a cardboard box	2			
2	Fold the cardboard box	5			
3	Rotate the cardboard box and place it on the table	4			
4	Take a plastic bag and insert it in the cardboard box	9			
5	Get the prepared box and place it in the fixture	5			
6	Start the equipment and wait until enough amount of chips is released	9			
7	Get the filled chips box and prepare it for sealing	9			
8	Take the sealing strip and seal the plastic bag	4			
9	Fold the filled chips box, shake and rotate it	7			
10	Get the tape gun and seal the filled chips box	5			
11	Get the sealed chips box and place it on the pallet	7			
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
	Total:	66			

Layout work sequence

	DATE	OPR	TL	PM	MAINT	QA	SAFETY
Work shift A							
Work shift B							
Work shift C							
Issue 1							

[redacted]

Created by	Chalmers University of Technology	
Approved by		

Lock	Protective goggles	Protective shoes	Protective gloves	Hearing protection	Protective screen	Protective clothes	Protective helmet	Dust protection	

Figure 3: Conducted SOP concerning the manual packaging operation on packaging line 3.

Santa Maria	Standard Operating Procedure SOP	Department	Production	Date	03/05/2012
		Section	Chips line	Work sheet	S.O.P Master
Plant	Taco Plant	Process	Change of product type, line C2	Page	Page 1 of 2
Takt Time	N/A	Product	Taco chips		
Cycle time (Min)	7.52 min	Risk Assessment	N/A		

PRODUCE AGAINST BUFFER ● | SAFETY | ERGONOMICS | LARGE IMPACT ON QUALITY | QUALITY CONTROL

Step	Work step	Time - Element (Sec) Manual	Autom.	Step	"Key points" Safety, Quality, Cost, Technology
1	Turn off the packaging line by pressing the stop button	4			
2	Go up to the flavouring platform	27			
3	Put on the protection clothes	5			
4	Rotate the flavour container	7			
5	Remove the sensor from the container	2			
6	Get shovel, use it to empty the containera and return the shovel	12			
7	Change the setting of the falvouring machine	3			
8	Turn off the flavouring machine	2			
9	Disassemble the existing feeder housing	8			
10	Disassemble the existing spiral feeder	4			
11	Clean out the remaining flavour with the spiral feeder and return it	12			
12	Get the container and mount it on the existing one	13			
13	Lock all four fastners	11			
14	Palce the sensor in its position	2			
15	Get the the new sprial feeder and the feeder housing	13			
16	Mount the new spiral feeder on the flavouring machine	3			
17	Mount the new feeder housing on the flavouring machine	5			
18	Start the feeding equipment	3			
19	Check and stop the feeding equipment	3			
20	Get ladder and place it next to the flavouring machine	3			
21	Get flavour bags and put it on the ladder	14			
22	Get the knife and cut the bag	5			
23	Fold up the bags and climb up on the ladder	2			
24	Tilt the bag, empty its content in the container and discard the empty bag	4			
	Total:	167			

Layout work sequence

	DATE	OPR	TL	PM	MAINT	QA	SAFETY
Work shift A							
Work shift B							
Work shift C							
Issue 1							
Created by	Chalmers University of Technology						
Approved by							

Lock	Protective goggles	Protective shoes	Protective gloves	Hearing protection	Protective screen	Protective clothes	Protective helmet	Dust protection

	PRODUCE AGAINST BUFFER ● · SAFETY · ERGONOMICS · LARGE IMPACT ON QUALITY · QUALITY CONTROL	Page: Page 2 of 2				Date: 03/05/2012
Step	Work step	Time - Element (Sec)			"Key points" Safety, Quality, Cost, Technology	
		Manual	Autom.	Step		
25	Start the flavoruing machine and rotate the containor to its original position	5				
26	Get 3 more flavour bags and put them on the ladder	42				
27	Get the knife and cut the bags	16				
28	Fold up the bags and climb up on the ladder	6				
29	Tilt the bag, empty its content in the container and discard the empty bag	13				
30	Take off the protection clothes	9				
31	Go down and start the packaging line	28				
32	Discard a sufficient amount of bags from the line until the correct flavor is in the right foil	164				
33						
34						
35						
36						
37						
38						
39						
40						
41						
42						
43						
44						
45						
46						
47						
48						
49						
50						
51						
52						
53						
54						
55						
56						
	Total:	283				

Lock	Protective goggles	Protective shoes	Protective gloves	Hearing protection	Protective screen	Protective clothes	Protective helmet	Dust protection

Figure 4: Conducted SOP concerning the change of product type operation on packaging line 2.

Appendix G – AutoMod Entities

The following tables include production data that was gathered empirically and further statistical parameters that are based on Santa Maria's documented data from 2011.

Table 1: Resources created during the simulation and their properties.

Nr.	Resource name	Cycle time	Capacity	MTBF Mean time between failure	MTTR Mean time to repair
1	R_mixer (1)	360 sec	215 kg dough 2150 L_dough[1]	Weibull $\alpha=0.87131$ $\beta=38.917$	Weibull $\alpha=1.2328$ $\beta=26.15$
2	R_mixer (2)	360 sec	215 kg dough 2150 L_dough[1]	Weibull $\alpha=0.87131$ $\beta=38.917$	Weibull $\alpha=1.2328$ $\beta=26.15$
3	R_roller	360 sec	10 kg dough 100 L_dough[1]	Weibull $\alpha=0.95685$ $\beta=11.2$	Lognormal $\sigma=0.95179$ $\mu=2.6638$
4	R_former	0.42 sec	44 chips 1 L_chips(1)[2]	Weibull $\alpha=0.88564$ $\beta=28.901$	Lognormal $\mu=1.7055$ $\sigma=1.0223$
5	R_baker	20.35 sec	3960 chips 99 L_chips (1)[3]	Lognormal $\mu=1.5557$ $\sigma=1.1781$	Lognormal $\mu=3.0776$ $\sigma=1.166$
6	R_air_dryer	213 sec	8550 chips 200 L_chips (1)[4]	Uniform a=-458.24 b=913.84	Uniform a=-151.94 b=383.94
7	R_fryer	137 sec	8550 chips 200 L_chips (1)[5]	Gamma $\alpha=1.4534$ $\beta=18.481$	Lognormal $\mu=2.8253$ $\sigma=1.2826$
8	R_flavorer (1)	30 sec	8 chips bags 40 L_chips (2)[6]	Gamma $\alpha=1.3963$ $\beta=29.516$	Gamma $\alpha=0.66708$ $\beta=14.701$
9	R_sealer (1)	12 sec	6 chips bags 30 L_chips (2)[7]	Exponential $\lambda=0.32785$	Lognormal $\mu=1.6806$ $\sigma=1.1591$
10	R_controller (1)	3.5 sec	3 chips bags 3 L_chips_bag (1)[8]	Lognormal $\mu=0.74557$ $\sigma=0.97462$	Lognormal $\mu=1.0642$ $\sigma=0.94849$
11	R_box_producer	7 sec	3 boxes 3 L_box[9]	Weibull $\alpha=1.0137$ $\beta=3.184$	Lognormal $\mu=1.8984$ $\sigma=1.065$
12	R_packager (1)	53 sec	4 chips boxes 4 L_chips_box (1)[10]	Weibull $\alpha=0.76428$ $\beta=3.1489$	Lognormal $\mu=2.0036$ $\sigma=1.0862$
13	R_labeler (1)	0.209 sec	1 chips box 1 L_chips_box (1)[10]	Gamma $\alpha=0.58489$ $\beta=61.497$	Gamma $\alpha=0.64937$ $\beta=14.533$
14	R_palleter (1)	100 sec	12 chips boxes 12 L_chips_box (1)[11]	Weibull $\alpha=0.98077$ $\beta=10.719$	Lognormal $\mu=1.7345$ $\sigma=1.4116$
15	R_flavorer (2)	20 sec	15 chips bags 30 L_chips (3)[12]	Gamma $\alpha=1.2167$ $\beta=67.749$	Exponential $\lambda=0.1165$
16	R_sealer (2)	6 sec	7 chips bags 14 L_chips (3)[13]	Normal $\mu=2.4855$ $\sigma=5.8596$	Lognormal $\mu=2.0277$ $\sigma=1.1329$

17	R_controller (2)	2.09 sec	4 chips bags 4 L_chips_bag (1)[14]	Weibull α=1.0046 β=3.1118	Lognormal μ=1.5443 σ=1.0308
18	R_packager (2)	34 sec	4 chips boxes 4 L_chips_box (2)[15]	Normal μ=2.5978 σ=5.8037	Lognormal μ=2.6096 σ=1.1077
19	R_labeler (2)	0.209 sec	1 chips box 1 L_chips_box (2)[15]	Weibull α=0.6583 β=45.271	Weibull α=0.77845 β=11.407
20	R_palleter (2)	180 sec	20 chips boxes 20 L_chips_box (2)[16]	Lognormal μ=1.709 σ=1.2425	Lognormal μ=1.7506 σ=1.391
21	R_wrapper	76 sec	1 chips pallet 1 L_chips_pallet (1/2)[17]	Weibull α=0.90537 β=24.668	Weibull α=0.81312 β=24.886
22	R_worker (1)	Varying	Responsible for manufacturing section[18]	-	-
23	R_worker (2)	Varying	Responsible for packaging line 1 [19]	-	-
24	R_worker (3)	Varying	Responsible for packaging line 2 [20]	-	-

1. Each L_dough represents 100 g dough.
2. There are 4 existing chips rows with 11 chips in each row. Measured weight of each non-baked chips is 2.5 g.
3. The baking belt is 1800 cm long. There is a chips row in each 5 cm and there are 11 chips in each row.
4. The air-drying belt has 5 levels and there are approximately 20 bags of 200 g on each level.
5. The capacity of the frying equipment is assumed to be the same as the air-drying belt.
6. 100 g chips is represented by 1 L_chips (2). 8 chips bags with 500 g chips in each are represented by 40 L_chips (2).
7. 100 g chips is represented by 1 L_chips (2). 6 chips bags with 500 g chips in each are represented by 30 L_chips (2).
8. Each chips bag consists of 500 g chips.
9. L_box represents a cardboard box belonging to packaging line 1 (producing chips bags of 500 g).
10. Each chips box consists of 12 chips bags with 500 g chips.
11. Each chips pallet (500 g) consists of 12 chips boxes.
12. 100 g chips are represented by 1 L_chips (3). 15 chips bags with 200 g chips in each are represented by 30 L_chips (3).
13. 100 g chips are represented by 1 L_chips (3). 7 chips bags with 200 g chips in each are represented by 14 L_chips (3).
14. Each chips bag consists of 200 g chips.
15. Each chips box consists of 15 chips bags with 200 g chips.
16. Each chips pallet (200 g) consists of 20 chips boxes.
17. The wrapping equipment operates both types of pallets.
18. Operator 1 is responsible for the whole manufacturing section.
19. Operator 2 is responsible for the whole packaging line 1, which manufactures chips bags of 500 g.
20. Operator 3 is responsible for the whole packaging line 2, which manufactures chips bags of 200 g.

Table 2: Queues created during the simulation and their properties.

Nr.	Queue name	Capacity	Load type
1	Q_ingredients	Infinite	∞ L_ingredients[1]
2	Q_mixer_wait (1)	Infinite	∞ L_ingredients[1]
3	Q_mixer_wait (2)	Infinite	∞ L_ingredients[1]
4	Q_mixer (1)	215 kg dough	2150 L_dough[2]
5	Q_mixer (2)	215 kg dough	2150 L_dough[2]
6	Q_roller_wait	215 kg dough	2150 L_dough[3]
7	Q_roller	10 kg dough	100 L_dough[2]
8	Q_former_wait	1.5 kg dough	15 L_dough[2]
9	Q_waste (1)	Infinite	∞ L_dought[4]
10	Q_former	44 chips	1 L_chips(1)[5]
11	Q_baker_wait	198 chips	5 L_chips(1)[6]
12	Q_baker	3960 chips	99 L_chips (1)[7]
13	Q_air_dryer_wait	1540 chips	36 L_chips (1)[8]
14	Q_air_dryer	8550 chips	200 L_chips (1)[9]
15	Q_fryer_wait	400 chips	9 L_chips (1)[10]
16	Q_waste (2)	60 kg chips	600 L_chips (1)[11]
17	Q_fryer	8550 chips	200 L_chips (1)[12]
18	Q_splitting	200 kg chips	200 L_chips (1)[13]
19	Q_waste (3)	60 kg chips	600 L_chips (1)[11]
20	Q_flavorer_wait (1)	5 chips bags	25 L_chips (2)[14]
21	Q_flavorer (1)	8 chips bags	40 L_chips (2)[15]
22	Q_sealer_wait (1)	4 chips bags	20 L_chips (2)[14]
23	Q_sealer (1)	6 chips bags	30 L_chips (2)[16]
24	Q_controller_wait (1)	1 chips bags	1 L_chips_bag (1)[17]
25	Q_controller (1)	3 chips bags	3 L_chips_bag (1)[17]
26	Q_waste (4)	60 kg chips	120 L_chips_bag (1)[11]
27	Q_packager_wait (1)	7 chips bags	7 L_chips_bag (1)[17]
28	Q_waste (6)	50 chips bags	50 L_chips_bag (1)[17]

29	Q_box_producer	3 boxes	3 L_box[18]
30	Q_box	25 boxes	25 L_box[19]
31	Q_packager (1)	4 chips boxes	4 L_chips_box (1)[20]
32	Q_labeler_wait (1)	1 chips boxes	1 L_chips_box (1)[20]
33	Q_labeler (1)	1 chips box	1 L_chips_box (1)[20]
34	Q_palleter_wait (1)	2 chips box	2 L_chips_box (1)[20]
35	Q_palleter (1)	12 chips boxes	12 L_chips_box (1)[21]
36	Q_flavorer_wait (2)	10 chips bags	20 L_chips (3)[22]
37	Q_flavorer (2)	15 chips bags	30 L_chips (3)[23]
38	Q_sealer_wait (2)	9 chips bags	18 L_chips (3)[22]
39	Q_sealer (2)	7 chips bags	14 L_chips (3)[24]
40	Q_controller_wait (2)	1 chips bags	1 L_chips_bag (2)[25]
41	Q_controller (2)	4 chips bags	4 L_chips_bag (2)[25]
2642	Q_waste (5)	60 kg chips	300 L_chips_bag (2)[11]
43	Q_packager_wait (2)	6 chips bags	6 L_chips_bag (2)[25]
44	Q_waste (7)	35 chips bags	35 L_chips_bag (2)[25]
45	Q_packager (2)	4 chips boxes	4 L_chips_box (2)[26]
46	Q_labeler_wait (2)	1 chips boxes	1 L_chips_box (2)[26]
47	Q_labeler (2)	1 chips box	1 L_chips_box (2)[26]
48	Q_palleter_wait (2)	35 chips box	35 L_chips_box (2)[26]
49	Q_palleter (2)	20 chips boxes	20 L_chips_box (2)[27]
50	Q_wrapper_wait	5 chips pallet	5 L_chips_pallet (1/2)[28]
51	Q_wrapper	1 chips pallet	1 L_chips_pallet (1/2)[28]
52	Q_final	16 chips pallet	16 L_chips_pallet (1/2)[28]

1. It is assumed that raw material is always available.
2. Each L_dough represents 100 g dough.
3. The capacity of the mixing chamber that waits for the rolling operation.
4. Unlimited amount of waste in dough form can be placed on the floor.
5. There are 4 chips rows with 11 chips in each row. Measured weight of each non-baked chips is 2.5 g.
6. There are 18 chips rows with 11 chips in each row.
7. The baking belt is 1800 cm long. There is a chips row in each 5 cm and there are 11 chips in each row.
8. There are 22 cells with approximately 70 chips in each cell.
9. The air-drying belt has 5 levels and there are approximately 20 bags of 200 g on each level.
10. This capacity is based on assumptions.
11. This capacity is based on information from an operator.
12. The capacity of frying equipment is assumed to be the same as the air-drying belt.
13. This capacity of chips amount in the elevating conveyor moved to the flavouring platform.

14. This capacity is based on assumptions. The weight of each bag is 500 g.
15. 100 g chips are represented by 1 L_chips (2). 8 chips bags with 500 g chips in each are represented by 40 L_chips (2).
16. 100 g chips are represented by 1 L_chips (2). 6 chips bags with 500 g chips in each are represented by 30 L_chips (2).
17. Each chips bag consists of 500 g chips.
18. L_box represents a cardboard box belonging to packaging line 1 (producing chips bags of 500 g).
19. 25 finished boxes waiting to be used in the packaging process.
20. Each chips box consists of 12 chips bags with 500 g chips.
21. Each chips pallet (500 g) consists of 12 chips boxes.
22. This capacity is based on assumptions. The weight of each bag is 200 g.
23. 100 g chips are represented by 1 L_chips (3). 15 chips bags with 200 g chips in each are represented by 30 L_chips (3).
24. 100 g chips are represented by 1 L_chips (3). 7 chips bags with 200 g chips in each are represented by 14 L_chips (3).
25. Each chips bag consists of 200 g chips.
26. Each chips box consists of 15 chips bags with 200 g chips.
27. Each chips pallet (200 g) consists of 20 chips boxes.
28. The equipment operates both types of pallets.

Table 3: Variables created during the simulation and their properties.

Nr.	Variable name	Critical number	Responsible operator	Time for refilling
1	V_role (1)	3411 bags[1]	Operator 2	Lognormal μ=1.0248 σ=0.60413
2	V_role (2)	5280 bags[2]	Operator 3	Weibull α=1.7113 β=5.9217
3	V_cardboard (1)	210 cardboard boxes	Operator 2	180 sec
4	V_cardboard (2)	210 cardboard boxes	Operator 3	30 sec
5	V_cover	80 covers	Operator 2	30 sec
6	V_glue (1)	400 glue pieces[3]	Operator 2	180 sec
7	V_glue (2)	400 glue pieces[3]	Operator 2	30 sec
8	V_glue (3)	400 glue pieces[3]	Operator 3	30 sec
9	V_label (1)	3500 labels	Operator 2	180 sec
10	V_label (2)	3500 labels	Operator 3	180 sec
11	V_pallet	15 pallets	Operator 2 and 3	80 sec

1. Each foil roll is 1450 m long and each bag is 0.425 m long.
2. Each foil roll is 1600 m long and each bag is 0.303 m long.
3. Each glue piece is enough for producing 5 cardboard-boxes.

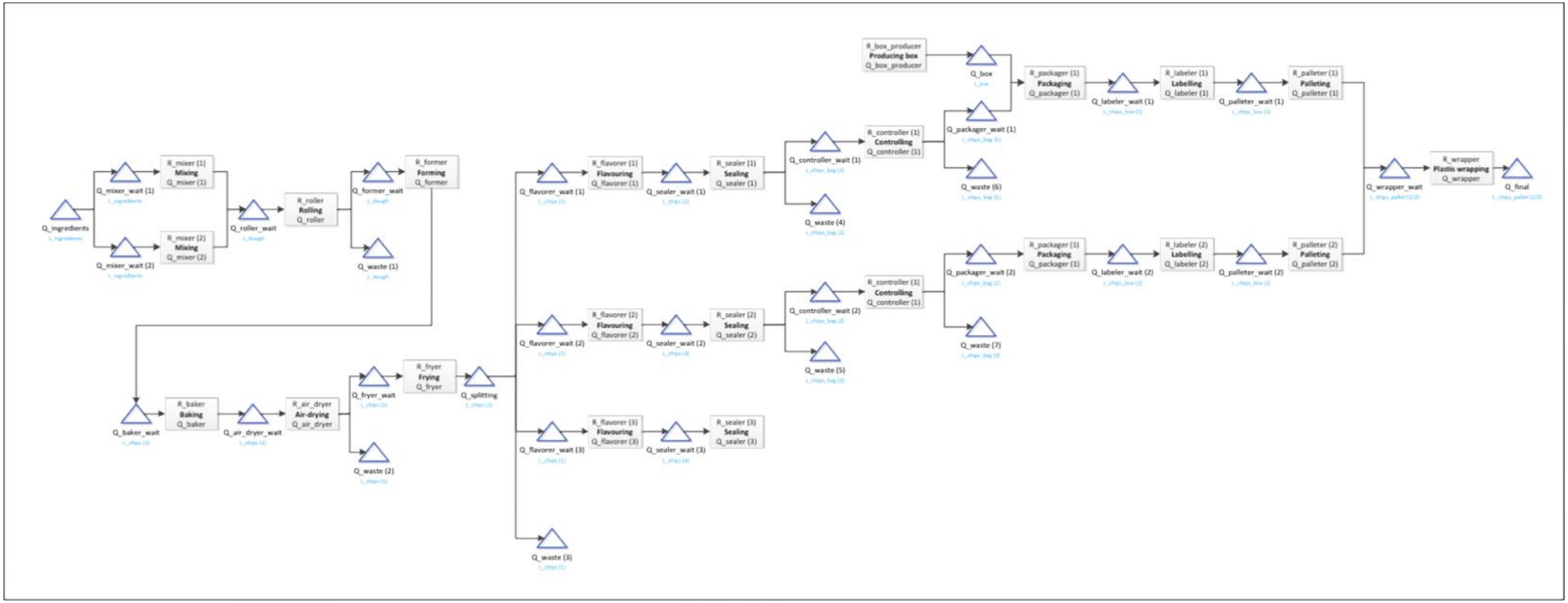

Figure 1: A general overview for all created queues, resources and loads in AutoMod. A larger image is available in the following pages.

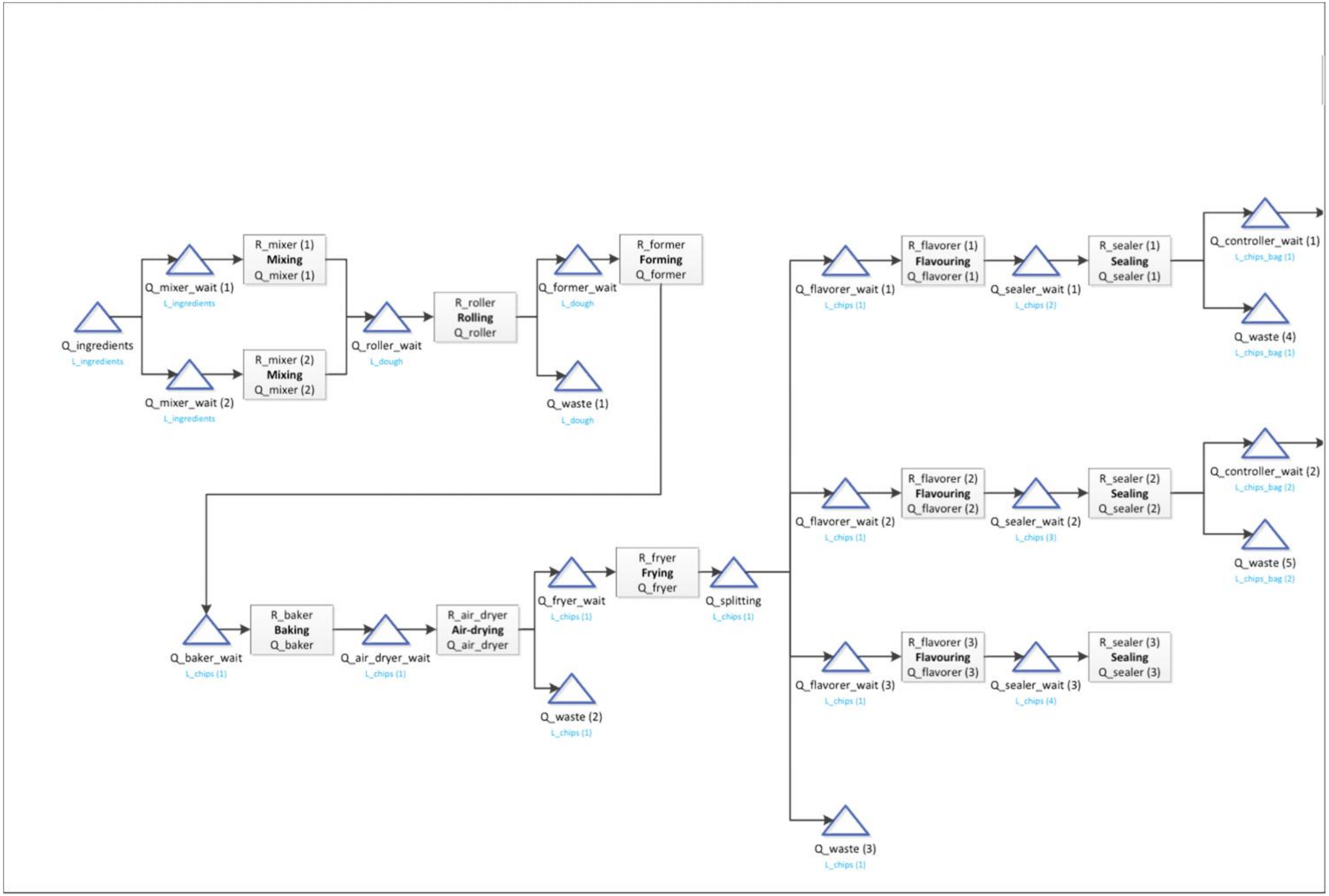

Figure 2: A general overview for all created queues, resources and loads in AutoMod. (First part)

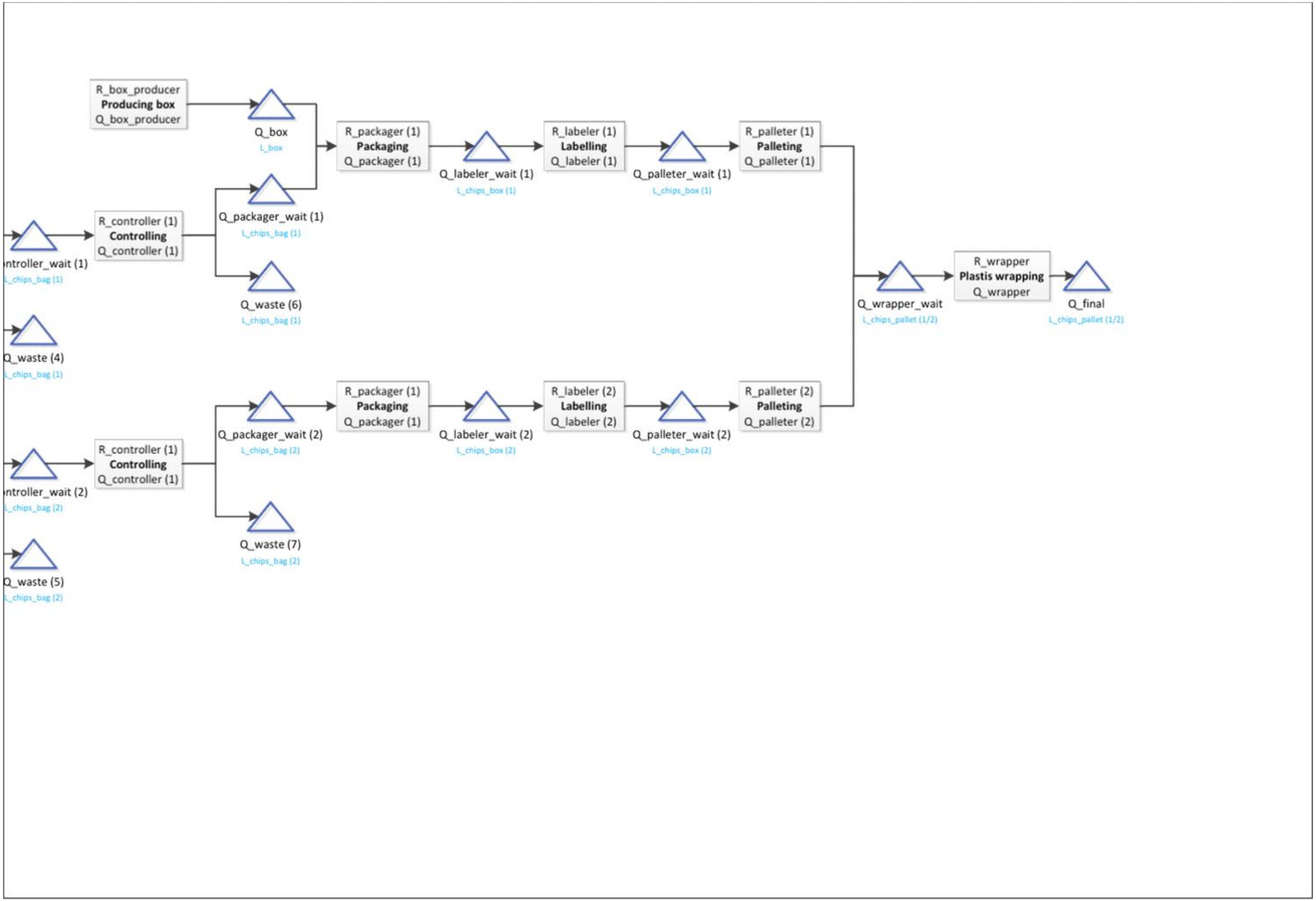

Figure 3: A general overview for all created queues, resources and loads in AutoMod. (Second part)

Appendix H – AutoMod Source File

```
begin P_init arriving procedure                                   //Collected input data is selected in this process
        set V_cycle_mixer = 360/2150
        set V_cycle_roller = 420/100
        set V_cycle_forming = 0.42/1
        set V_cycle_baking = 20.35/99
        set V_cycle_air_drying = 213/200
        set V_cycle_frying = 137/200
        set V_cycle_flavorer(1) = 30/40
        set V_cycle_flavorer(2)= 20/30
        set V_cycle_sealer(1) = 2/14
        set V_cycle_sealer(2) = 0.86/30
        set V_cycle_packager(1) = 53/5
        set V_cycle_packager(2) = 34/4
        set V_cycle_palleter(1) = 100/12
        set V_cycle_palleter(2) = 180/20
        set V_cycle_wrapper = 76/1
        set V_cycle_box_producer = 21/3
        set V_cycle_control(1) = 3.5/3
        set V_cycle_control(2) = 2.09/4
        set V_cycle_label = 0.209/1
        move into Q_ingredients
        send to P_mixing_ingredients
end

//---------------------------Production type---------------------
begin P_production_type arriving procedure                        //The process where some equipment are deactivated
        take down R_flavorer(3)
        take down R_sealer(3)
end

//------------------------------Mixing---------------------------
begin P_mixing_ingredients arriving procedure
        choose a queue from among Q_mixer_wait(1), Q_mixer_wait(2)   //The mixing machine which is free is selected
        whose current loads is minimum
        save choice as A_qmixer
        move into A_qmixer
        set A_mixerindex = A_qmixer index
        move into Q_mixer(A_mixerindex)                              //Ingredients move to the selected mixing equipment
        use R_mixer(A_mixerindex) for V_cycle_mixer sec              //Process time/cycle time for the mixing equipment
        set load type = L_dough                                      //Ingredients are mixed to a dough
        send to P_rolling
end
```

```
//-----------------------------Rolling---------------------------
begin P_rolling arriving procedure
        move into Q_roller_wait
        move into Q_roller                          //Dough moves to the rolling equipment
        use R_roller for V_cycle_roller sec         //Process time/cycle time for the rolling equipment
        set A_random(1) to oneof (98:1, 2:2)        //2% chips are discarded and 98% is approved
        if A_random(1) = 2 then
                send to P_waste_1
        send to P_forming
end

begin P_waste_1 arriving procedure                  //Trash bin for chips which are discarded
        move into Q_waste(1)
        send to die
end

//-----------------------------Forming--------------------------
begin P_forming arriving procedure
        move into Q_former_wait
        move into Q_former                          //Dough moves to the forming equipment
        use R_former for V_cycle_forming sec        //Process time/cycle time for the forming equipment
        set load type = L_chips(1)                  //Dough is transferred to unbaked chips
        send to P_baking
end

//-----------------------------Baking---------------------------
begin P_baking arriving procedure
        move into Q_baker_wait
        move into Q_baker                           //Formed dough moves to the baking equipment
        use R_baker for V_cycle_baking sec          //Process time/cycle time for the baking equipment
        send to P_air_drying
end

//---------------------------Air drying-------------------------
begin P_air_drying arriving procedure
        move into Q_air_dryer_wait
        move into Q_air_dryer                       //Baked chips move to the air-drying equipment
        use R_air_dryer for V_cycle_air_drying sec  //Process time/cycle time for the air drying equipment
        set A_random(2) to oneof (98:1, 2:2)        //2% chips are discarded and 98% is approved
        if A_random(1) = 2 then
                send to P_waste_2
        send to P_frying
end

begin P_waste_2 arriving procedure                  //Trash bin for chips which are discarded
        move into Q_waste(2)
        send to die
```

```
end

//----------------------------Frying-------------------------
begin P_frying arriving procedure
        move into Q_fryer_wait
        move into Q_fryer                                   //Unfried chips move to the frying machine
        use R_fryer for V_cycle_frying sec                  //Process time/cycle time for the frying equipment
        move into Q_splitting                               //Fried chips are distribute from this queue
        send to P_flavoring
end

//--------------------------Flavoring------------------------
begin P_flavoring arriving procedure
        if Q_flavorer_wait(1) remaining space = 0 and Q_flavorer_wait(2) remaining space = 0 then begin     //Available space in different flavoring machines are controlled
                move into Q_waste(3)                        //Unflavored chips move to the trash bin
                send to die
        end
        else begin
                choose a queue from among Q_flavorer_wait(1), Q_flavorer_wait(2)     //The flavoring machine which is free is selected
                whose current loads is minimum
                save choice as A_qflavorer
                set A_index = A_qflavorer index
                move into Q_flavorer_wait(A_index)
                move into Q_flavorer(A_index)               //Unflavored chips move to the selected machine
                use R_flavorer(A_index) for V_cycle_flavorer(A_index) sec     //Process time/cycle time for the selected flavoring equipment
                set load type = L_chips(A_index+1)          //Unflavored chips is transformed into flavored chips
                send to P_sealing
        end
end

//---------------------------Sealing-------------------------
begin P_sealing arriving procedure
        move into Q_sealer_wait(A_index)
        move into Q_sealer(A_index)                         //Flavored chips move to the selected sealing machine
        use R_sealer(A_index) for V_cycle_sealer(A_index) sec     //Process time/cycle time for the selected sealing equipment
        if A_index = 1 then begin                           //This event is true if the load is a bag with 500g chips
                inc V_role(1) by 1                          //One 500g bag is used
                if V_role(1) > (3411*5) then begin          //The bag roll is enough to 3411 bags (Each load is 100g!)
                        if OL_waste(4) current loads = 14 then begin     //3 bags are discarded when the bag roll is changed
                                take down R_sealer(1)       //The sealing equipment is switched off
                                use R_worker(2) for lognormal 1.0248 , 0.60413  min     //Operator 2 is responsible for changing the bag roll
                                set V_role(1) to 0          //A new bag roll is inserted
                                bring up R_sealer(1)        //The sealing equipment is switched on
                                order 14 loads from OL_waste(4) to P_waste_4     //3 discarded bags are moved to the trash bin
                                send to P_waste_4
                        end
                else
```

```
                        wait to be ordered on OL_waste(4)                   //500g chips bags wait here until the total number is 3

            end
            if OL_500_bag current loads = 4 then begin
                    order 4 loads from OL_500_bag to die                    //4 loads are killed and the last one represents a 500g chips box
                    in case order not filled backorder on OL_500_bag
                    send to P_control
            end
            else
                    wait to be ordered on OL_500_bag                        //Loads wait here until the total number is 4
        end
        else begin                                                          //This event is true if the load is a bag with 200g chips
            inc V_role(2) by 1                                              //One 200g bag is used
            if V_role(2) > (5280*2) then begin                              //The bag roll is enough to 5280 bags (Each load is 100g!)
                    if OL_waste(5) current loads = 5 then begin             //3 bags are discarded when the bag roll is changed
                        take down R_sealer(2)                               //The sealing equipment is switched off
                        use R_worker(3)for weibull 1.7113 , 5.9217 min      //Operator 3 is responsible for changing the bag roll
                        set V_role(2) to 0                                  //A new bag roll is inserted
                        bring up R_sealer(2)                                //The sealing equipment is switched on
                        order 5 loads from OL_waste(5) to P_waste_5         //3 discarded bags are moved to the trash bin
                        send to P_waste_5
                    end
                    else
                        wait to be ordered on OL_waste(5)                   //200g chips bags wait here until the total number is 3
            end
            if OL_200_bag current loads = 1 then begin
                    order 1 loads from OL_200_bag to die                    //1 load is killed and the other one represents a 200g chips box
                    in case order not filled backorder on OL_200_bag
                    send to P_control
            end
            else
                    wait to be ordered on OL_200_bag                        //Loads wait here until the total number is 1
        end
end

begin P_waste_4 arriving procedure                                          //Trash bin for 500g bags which are discarded when the bag roll is changed
        move into Q_waste(4)
        send to die
end

begin P_waste_5 arriving procedure                                          //Trash bin for 200g bags which are discarded when the bag roll is changed
      move into Q_waste(5)
        send to die
end

//----------------------------Control--------------------------
begin P_control arriving procedure
```

```
            move into Q_controller_wait(A_index)
            move into Q_controller(A_index)                              //Chips bags move to the selected controller
            use R_controller(A_index) for V_cycle_control(A_index) sec   //Process time/cycle time for the selected controlling equipment
            set A_random(2) to oneof (98:1, 2:2)                         //2% bags are discarded and 98% is approved
            if A_random(2) = 2 then begin
                        if A_index = 1 then                              //If selected bag is 500g
                                    send to P_waste_6
                        else                                             //If selected bag is 200g
                                    send to P_waste_7
            end
            move into Q_packager_wait(A_index)
            set load type = L_chips_bag(A_index)                         //One approved chips bag is manufactured
            send to P_packaging
end

begin P_waste_6 arriving procedure                                       //Trash bin for 500g bags which are discarded
            if Q_waste(6) remaining space > 14 then                      //The free space in the selected trash bin is controlled
                        use R_worker(2) for 300 sec                      //Operator 2 is responsible for emptying the trash bin
            move into Q_waste(6)
            send to die
end

begin P_waste_7 arriving procedure                                       //Trash bin for 200g bags which are discarded
            if Q_waste(7) remaining space > 33 then                      //The free space in the selected trash bin is controlled
                        use R_worker(3) for 300 sec                      //Operator 3 is responsible for emptying the trash bin
            move into Q_waste(7)
            send to die
end

//-------------------------Producing box---------------------
begin P_producing_box arriving procedure
                        if Q_box remaining space > 0 then begin          //Boxes are made if next buffer has free space
                                    inc V_glue(1) by 1                   //Some glue is used from the selected glue pot
                                    inc V_cardboard(1) by 1              //One cardboard box is used
                                    move into Q_box_producer             //One cardboard box is moved to the box producer
                                    use R_box_producer for V_cycle_box_producer sec   //Process time/cycle time for the box producing equipment
                                    move into Q_box
                                    wait to be ordered on OL_box         //Finished boxes wait here until they are needed in the next process
                                    if V_glue(1) > 2000 or V_cardboard(1) > 210 then begin   //Amount of available glue and number of available cardboard boxes are controlled
                                                use R_worker(2) for 180 sec       //Operator 2 is responsible for the box producing machine
                                                set V_glue(1) to 0                //Glue pot is filled
                                                set V_cardboard(1) to 0           //Cardboard boxes are loaded into the box producing machine

                                    end

                        end
                        send to die
```

```
end

//---------------------------Packaging-------------------------
begin P_packaging arriving procedure
    move into Q_packager_wait(A_index)
    if A_index = 1 then begin                                   //This event is true if the load is a bag with 500g chips
        dec V_cover by 1
        if V_cover > 80 then begin                              //Number of available covers are controlled
            use R_worker(2)for 30 sec                           //Operator 2 is responsible for loading of covers
            set V_cover = 0                                     //80 covers are loaded into the packaging machine
        end
        dec V_glue(A_index+1) by 1                              //Some glue is used from the selected glue pot
        if V_glue(A_index+1) > 2000 then begin                  //Amount of available glue is controlled
            use R_worker(2)for 30 sec                           //Operator 2 is responsible for filling of glue
            set V_glue(A_index+1) = 0                           //Glue pot is filled
        end
        order 1 load from OL_box to die                         //Loads wait here until the total number is 4
        move into Q_packager(A_index)                           //500g chips bags are moved to the selected packaging equipment
        use R_packager(A_index) for V_cycle_packager(A_index)   //Process time/cycle time for the selected packaging equipment
        if OL_500_box current loads = 11 then begin
            order 11 loads from OL_500_box to die               //11 loads are killed and the last one represents a chips box
            in case order not filled backorder on OL_500_box
            set load type = L_chips_box(A_index)                //A box containing 500g chips bags is manufactured
            send to P_labeling
        end

        else
            wait to be ordered on OL_500_box                    //500g chips bags wait here until the total number is 11
    end
    else begin                                                  //This event is true if the load is a bag with 200g chips
        dec V_cardboard(A_index) by 1                           //One cardboard box is used
        if V_cardboard(A_index) < 1 then begin                  //Number of available cardboard boxes are controlled
            use R_worker(3)for 30 sec                           //Operator 3 is responsible for filling of cardboard boxes
            set V_cardboard(A_index) = 210                      //210 cardboard boxes are loaded into the packaging machine
        end
        dec V_glue(A_index+1) by 1                              //Some glue is used from the selected glue pot
        if V_glue(A_index+1) > 2000 then begin                  //Amount of available glue is controlled
            use R_worker(3)for 30 sec                           //Operator 2 is responsible for filling of glue
            set V_glue(A_index+1) = 0                           //Glue pot is filled
        end
        move into Q_packager(A_index)                           //200g chips bags are moved to the selected packaging equipment
        use R_packager(A_index) for V_cycle_packager(A_index)   //Process time/cycle time for the selected packaging equipment
        if OL_200_box current loads = 15 then begin
            order 15 loads from OL_200_box to die               //15 loads are killed and the last one represents a chips box
            in case order not filled backorder on OL_200_box
            set load type = L_chips_box(A_index)                //A box containing 200g chips bags is manufactured
            send to P_labeling
```

```
                    end
                    else
                              wait to be ordered on OL_200_box              //200g chips bags will wait here until the total number is 19
          end
end

//--------------------------Labeling---------------------------
begin P_labeling arriving procedure
          move into Q_labeler_wait(A_index)
          move into Q_labeler(A_index)                              //Finished chips bags are moved to the selected labeling equipment
          inc V_label(A_index) by 1                                 //A label is used from the selected labeling equipment
          if V_label(A_index) > 3500 then begin                     //The label roll is enough to 3500 boxes
                    take down R_labeler(A_index)
                    use R_worker(A_index+1) for 180 sec             //The selected operator is responsible for loading of new label roll
                    set V_label(A_index) = 0                        //A new label roll is inserted
                    bring up R_labeler(A_index)
          end
          use R_labeler(A_index) for V_cycle_label                  //Process time/cycle time for the selected labeling equipment
          send to P_palleting
end

//---------------------------Palleting-------------------------
begin P_palleting arriving procedure
          move into Q_palleter_wait(A_index)
          inc V_pallet by     1                                     //A pallet is used
          if V_pallet > 15 then begin                               //Number of available pallets is controlled
                    set A_test to oneof (50:1, 50:2)                //Both operator 2 and 3 are responsible for loading of pallets
                    if A_test = 1 then
                              use R_worker(2) for 80 sec            //Loading of pallets is divided equally
                    else
                              use R_worker(3) for 80 sec
                    set V_pallet = 0                                //15 pallets are loaded into the palleting machine
          end
          if A_index = 1 then begin                                 //This event is true if the load is a box with 500g bags
                    if OL_500_pallet current loads = 11 then begin
                              order 11 loads from OL_500_pallet to die          //11 loads are killed and the last one represents a pallet
                              in case order not filled backorder on OL_500_pallet
                              set load type = L_chips_pallet(A_index)          //A pallet with 500g boxes is manufactured
                    end
                    else
                              wait to be ordered on OL_500_pallet              //Boxes will wait here until the total number is enough for a pallet
          end
          else begin                                                //This event is true if the load is a box with 200g bags
                    if OL_200_pallet current loads = 19 then begin
                              order 19 loads from OL_200_pallet to die          //19 loads are killed and the last one represents a pallet
                              in case order not filled backorder on OL_200_pallet
                              set load type = L_chips_pallet(A_index)          //A pallet with 200g boxes is manufactured
```

```
                end

                else
                        wait to be ordered on OL_200_pallet                //Boxes will wait here until the total number is enough for a pallet
        end
        move into Q_palleter(A_index)                                      //Finished chips bags are moved to the selected palleting equipment
        use R_palleter(A_index) for V_cycle_palleter(A_index)              //Process time/cycle time for the selected palleting equipment
        send to P_wrapping
end

//---------------------------Wrapping-------------------------
begin P_wrapping arriving procedure
        move into Q_wrapper_wait
        move into Q_wrapper                                                //Finished chips pallets are moved to the wrapping equipment
        use R_wrapper for V_cycle_wrapper sec                              //Process time/cycle time for the wrapping equipment
        move into Q_final                                                  //All finished pallets are moved to this queue
        send to die
end

//---------------------------Downtimes-------------------------
begin P_DownTime_mixer arriving procedure                                  //Downtime for R_mixer(1) and R_mixer(2)
        while 1=1 do begin
                set A_random_mixer to oneof (50:1, 50:2)                   //Same usage statistics for both mixers
                if A_random_mixer = 1 then begin
                        wait for weibull (0.87131/8) , (38.917/8) hr       //MTBF for R_mixer(1)
                        take down R_mixer(1)
                        use R_worker(1) for weibull 1.2328 , 26.15 min     //MTTR for R_mixer(1)
                        bring up R_mixer(1)
                end
                else begin
                        wait for weibull (0.87131/8) , (38.917/8) hr       //MTBF for R_mixer(2)
                        take down R_mixer(2)
                        use R_worker(1) for weibull 1.2328 , 26.15 min     //MTTR for R_mixer(2)
                        bring up R_mixer(2)
                end
        end
end

begin P_DownTime_roller arriving procedure                                 //Downtime for R_roller
        while 1=1 do begin
                wait for weibull (0.95685/8) , (11.2/8) hr                 //MTBF for R_roller
                take down R_roller
                use R_worker(1) for lognormal 2.6638 , 0.95179 min         //MTTR for R_roller
                bring up R_roller
        end
end
```

```
begin P_DownTime_former arriving procedure                                        //Downtime for R_former
        while 1=1 do begin
                wait for weibull (0.88564/8) , (28.901/8) hr                      //MTBF for R_former
                take down R_former
                use R_worker(1) for lognormal 1.7055 , 1.0223 min                 //MTTR for R_former
                bring up R_former
        end
end

begin P_DownTime_baker arriving procedure                                         //Downtime for R_baker
    while 1=1 do begin
                wait for lognormal (1.5557/8) , (1.1781/8) hr                     //MTBF for R_baker
                take down R_baker
                use R_worker(1) for lognormal 3.0776 , 1.166 min                  //MTTR for R_baker
                bring up R_baker
        end
end

begin P_DownTime_air_dryer arriving procedure                                     //Downtime for R_air_dryer
        while 1=1 do begin
                wait for uniform (913.84/8) , (-458.24/8) hr                      //MTBF for R_air_dryer
                take down R_air_dryer
                use R_worker(1) for uniform 383.94 , -151.94 min                  //MTTR for R_air_dryer
                bring up R_air_dryer
        end
end

begin P_DownTime_fryer arriving procedure                                         //Downtime for R_fryer
        while 1=1 do begin
                wait for gamma (1.4534/8) , (18.481/8) hr                         //MTBF for R_fryer
                take down R_fryer
                use R_worker(1) for lognormal 2.8253 , 1.2826 min                 //MTTR for R_fryer
                bring up R_fryer
        end
end

begin P_DownTime_flavorer_1 arriving procedure                                    //Downtime for R_flavorer(1)
        while 1=1 do begin
                wait for gamma (1.3963/8) , (29.516/8) hr                         //MTBF for R_flavorer(1)
                take down R_flavorer(1)
                use R_worker(2) for gamma 0.66708 , 14.701 min                    //MTTR for R_flavorer(1)
                bring up R_flavorer(1)
        end
end

begin P_DownTime_flavorer_2 arriving procedure                                    //Downtime for R_flavorer(2)
        while 1=1 do begin
```

```
                    wait for gamma (1.2167/8) , (67.749/8) hr                    //MTBF for R_flavorer(2)
                    take down R_flavorer(2)
                    use R_worker(3) for e 0.1165 min                             //MTTR for R_flavorer(2)
                    bring up R_flavorer(2)
          end
end

begin P_DownTime_sealer_1 arriving procedure                                     //Downtime for R_sealer(1)
          while 1=1 do begin
                    wait for e (0.32785/8) hr                                    //MTBF for R_sealer(1)
                    take down R_sealer(1)
                    use R_worker(2) for lognormal 1.6806 , 1.1591 min            //MTTR for R_sealer(1)
                    bring up R_sealer(1)
          end
end

begin P_DownTime_sealer_2 arriving procedure                                     //Downtime for R_sealer(2)
          while 1=1 do begin
                    wait for normal (2.4855/8) , (5.8596/8) hr                   //MTBF for R_sealer(2)
                    take down R_sealer(2)
                    use R_worker(3) for lognormal 2.0277 , 1.1329 min            //MTTR for R_sealer(2)
                    bring up R_sealer(2)
          end
end

begin P_DownTime_controller_1 arriving procedure                                 //Downtime for R_controller(1)
          while 1=1 do begin
                    wait for lognormal (0.74557/8) , (0.97462/8) hr              //MTBF for R_controller(1)
                    take down R_controller(1)
                    use R_worker(2) for lognormal 1.0642 , 0.94849 min           //MTTR for R_controller(1)
                    bring up R_controller(1)
          end
end

begin P_DownTime_controller_2 arriving procedure                                 //Downtime for R_controller(2)
          while 1=1 do begin
                    wait for weibull (1.0046/8) , (3.1118/8) hr                  //MTBF for R_controller(2)
                    take down R_controller(2)
                    use R_worker(3) for lognormal 1.5443 , 1.0308 min            //MTTR for R_controller(2)
                    bring up R_controller(2)
          end
end

begin P_DownTime_box_producer arriving procedure                                 //Downtime for R_box_producer
          while 1=1 do begin
                    wait for weibull (1.0137/8) , (3.184/8) hr                   //MTBF for R_box_producer
                    take down R_box_producer
```

```
                use R_worker(2) for lognormal 1.8984 , 1.065 min                //MTTR for R_box_producer
                bring up R_box_producer
        end
end

begin P_DownTime_packager_1 arriving procedure                                  //Downtime for R_packager(1)
        while 1=1 do begin
                wait for weibull (0.76428/8) , (3.1489/8) hr                    //MTBF for R_packager(1)
                take down R_packager(1)
                use R_worker(2) for lognormal 2.0036 , 1.0862 min               //MTTR for R_packager(1)
                bring up R_packager(1)
        end
end

begin P_DownTime_packager_2 arriving procedure                                  //Downtime for R_packager(2)
        while 1=1 do begin
                wait for normal (2.5978/8) , (5.8037/8) hr                      //MTBF for R_packager(2)
                take down R_packager(2)
                use R_worker(3) for lognormal 2.6096 , 1.1077 min               //MTTR for R_packager(2)
                bring up R_packager(2)
        end
end

begin P_DownTime_labeler_1 arriving procedure                                   //Downtime for R_labeler(1)
        while 1=1 do begin
                wait for gamma (0.58489/8) , (61.497/8) hr                      //MTBF for R_labeler(1)
                take down R_labeler(1)
                use R_worker(2) for gamma 0.64937 , 14.533 min                  //MTTR for R_labeler(1)
                bring up R_labeler(1)
        end
end

begin P_DownTime_labeler_2 arriving procedure                                   //Downtime for R_labeler(2)
        while 1=1 do begin
                wait for weibull (0.6583/8) , (45.271/8) hr                     //MTBF for R_labeler(2)
                take down R_labeler(2)
                use R_worker(3) for weibull 0.77845 , 11.407 min                //MTTR for R_labeler(2)
                bring up R_labeler(2)
        end
end

begin P_DownTime_palleter_1 arriving procedure                                  //Downtime for R_palleter(1)
        while 1=1 do begin
                wait for weibull (0.98077/8) , (10.719/8) hr                    //MTBF for R_palleter(1)
                take down R_palleter(1)
                use R_worker(2) for lognormal 1.7345 , 1.4116 min               //MTTR for R_palleter(1)
                bring up R_palleter(1)
```

```
            end
end

begin P_DownTime_palleter_2 arriving procedure                                        //Downtime for R_palleter(2)
            while 1=1 do begin
                        wait for lognormal (1.709/8) , (1.2425/8) hr                  //MTBF for R_palleter(2)
                        take down R_palleter(2)
                        use R_worker(3) for lognormal 1.7506 , 1.391 min              //MTTR for R_palleter(2)
                        bring up R_palleter(2)
            end
end

begin P_DownTime_wrapper arriving procedure                                           //Downtime for R_wrapper
            while 1=1 do begin
                        wait for weibull (0.90537/8) , (24.668/8) hr                  //MTBF for R_wrapper
                        take down R_wrapper
                        use R_worker(3) for weibull 0.81312 , 24.886 min              //MTTR for R_wrapper
                        bring up R_wrapper
            end
e
```

Appendix I – Concepts and Abbreviations

AutoMod

Software used for simulation purposes, which is used worldwide for simulation of production and logistics systems. The software is designed for detailed analysis of operations and flows (AutoMod, 2012).

Bottleneck

Physical constrictions, in terms of manufacturing resources that has less capacity than what is needed to fulfil the demand. Bottlenecks constrict or limit the flow of the overall process (Johansson and Mattsson, 2009).

Cycle-Time

The average time between entities of output emerging from a process (Bengtsson and Johansson, 2008).

DES – Discrete Event Simulation

Discrete Event Simulation can be defined as the depiction of a regular process or system over time for experimentation and evaluation purposes (Johansson, *Theoretical basics of Discrete Event Simulation*, 2010).

ERP – Enterprise Resource Planning

Management tool allowing an organization to use a system of integrated applications to manage the business. The system covers all aspects of an operation, including development, manufacturing, sales and marketing (Webopedia, 2012).

ErgoSAM – Ergonomic Sequence-based Activity and Method Analysis

An additional complementary function to SAM for detecting ergonomic problems during work (Laring, *Ergonomics and ErgoSAM*, 2010).

HTA – Hierarchical Task Analysis

Systematic method of analysing how a work task or material usage is carried out. The method involves a top down structure with the main goal as the starting point (Berlin, *Manual Work Load Analysis Methods Part 2,* 2011).

Jidoka

Japanese word used in Lean production that stands for visualizing problems. The principle of jidoka is building in quality during the manufacturing processes, which means that defected items are detected at an early stage and are not sent further (Liker, 2004).

JIT – Just-In-Time

Just-In-Time is an ideal production process where a specific amount of products are produced with the correct amount of materials needed, in the right time and at the correct place (Liker, 2004).

Kaizen

Continuous improvements in the essence of Lean production. In other words, working with small incremental changes continuously with aim of increasing the effectiveness of an activity to produce more value with less waste (Wänström, *Lean Principles*, 2011).

Lead-Time

The passed time from the initial phase of a project or production until the reaching of results (Bengtsson and Johansson, 2008).

MTM – Methods-time Measurement

Methods-Time Measurement is a predetermined time system developed in 1948 for analysing time studies of manual labour for productivity purposes (Freivalds, 2009).

Muda

The Japanese term for waste in the essence of Lean production. Muda, or waste, is defined as the non-value adding activities of the production (Liker, 2004).

OEE – Overall Equipment Efficiency

A unit that visualizes how well manufacturing equipment or an entire process is operating compared to the ideal plant. OEE is calculated by multiplying three independently measured values: Availability × Performance Rate × Quality (Bengtsson and Johansson, 2008).

One-Piece Flow

One-piece flow is the ideal pull-system state, meaning that only one item flows through different production steps. In a one-piece flow, there are no existing inventories and the production is only customer dependent (Liker, 2004).

PTS – Predetermined Time System

Time measuring method based on standard data including elemental times generated from different time studies (Freivalds, 2009).

Pull

Production or material movement based on the actual customer demand. Pull system is based on resources in progress ordering the necessary items from the previous resource in the production chain (Liker, 2004).

Push

Production system established on unanticipated customer demand. Push system is based on goods and raw material pushed forward in the production flow between different resources (Liker, 2004).

Run-Out Time

The time required until an order, or a number of products, are passed through a process or an operation (Johansson and Mattsson, 2009).

SAM – Sequence-Based Activity and Method Analysis

Considered as a form of MTM system for analysing time studies (Almström, *Predetermined time systems*, 2010).

SMED – Single-Minute Exchange of Die

Refers to a systematic method with the aim of reducing changeover times to single minutes (less than 10 minutes in total) (Almström, *Setup time reduction,* 2011), (Shingo, 1989).

SOP – Standard Operation Procedure

Written standard procedure used for carrying out operations in a given situation during the production (Gardtman, 2012).

TPS – Toyota Production System

Production philosophy and principles that originates from the Japanese automotive industry. TPS was initially developed and implemented by Toyota Motor Corporation (Liker, 2004).

TMU – Time Measurement Unit

Unit time values given in MTM analyses; 1 TMU corresponds 0.00001 hours or 0.036 seconds (Freivalds, 2009).

Value Adding Activities

The manufacturing of goods consists of process steps or tasks that the customer is willing to pay for (Bengtsson and Johansson, 2008).

VSM – Value Stream Map

A graphical representation of the material and information flow of a production process, that demonstrates all the steps required to produce a product or service (Liker, 2004).

WIP – Work In Progress

Refers to items that are under refinement in or between sequences of value adding resources (Johansson and Mattsson, 2009).